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Arbuscular Mycorrhizal (AM) and Dark Septate Endophyte (DSE) Fungal Association in Lycophytes and Ferns of the Kolli Hills, Eastern Ghats, Southern India

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ABSTRACT.—We examined the extent and type of arbuscular mycorrhizal (AM) and dark septate endophyte (DSE) fungal associations in three lycophyte and 44 fern species collected from three different sites in the Kolli Hills, Eastern Ghats, southern India. Of the 47 plant taxa (belonging to 21 families and 33 genera) examined, 46 had AM fungal and 33 had DSE fungal associations. But, fungal structures were absent in the aquatic fern *Azolla pinnata* (Azollaceae). This is the first report of AM and DSE fungal status for 16 and 28 species, respectively. Among terrestrial lycophytes and ferns, 26 species had dual association of both AM and DSE fungi, whereas 11 species had only AM fungal association. *Vittaria elongata* from epiphytic habitats had dual association of AM and DSE fungi. Likewise, *Cheilanthes tenuifolia* (saxicolous or terrestrial), *Cheilanthes opposita*, *Lepisorus nudus*, *Pyrrosia lanceolata* (terrestrial or epiphytic), and *Asplenium lanceolatum* (saxicolous or epiphytic) examined from different sites or habitats also had dual association of AM and DSE fungi. Seventy two percent of the mycorrhizal lycophytes and ferns had intermediate-type AM and 15 percent had both *Paris*- and intermediate-types at different sites. Significant variations in AM fungal structures were evident in 16 ferns occurring in two or more sites. Nine AM fungal spore morphotypes belonging to *Acaulospora*, *Funneliformis*, *Glomus*, *Gigaspora*, and *Sclerocystis* were found to be associated with lycophytes and ferns.

KEY WORDS.—arbuscular mycorrhiza, dark septate endophytic fungi, lycophytes, ferns, *Paris*-type, intermediate-type, Kolli Hills, Eastern Ghats

A wide range of soil fungi colonize plant roots, of which the most common and widespread are the arbuscular mycorrhizal (AM) fungi belonging to the phylum Glomeromycota. These fungi facilitate the uptake of nutrients, especially phosphorus (P) from nutrient deficient soils in exchange for host photosynthates (Smith and Read, 2008). Other benefits for plants from the fungal association include improved water relations, and tolerance to various abiotic and biotic stresses. Surveys of AM associations in vascular plants for over a century have established their wide spread occurrence (Brundrett, 2009 and references therein). Nevertheless, many plant taxa from natural ecosystems world-wide are yet to be examined for their mycorrhizal status. Despite their global distribution, the mycorrhizal status of lycophytes and ferns are scant. Kessler *et al.* (2010a) indicated that the 971 taxa of lycophytes and ferns whose mycorrhizal status was known to represent less than 10% of the global

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lycophyte and fern diversity. Since 2010, gametophytes and sporophytes of several lycophytes and ferns from Malaysia and Indonesia (Kessler *et al.*, 2010a), island of La Réunion (Kessler *et al.*, 2010b), Argentina (Fernandez *et al.*, 2010; 2012; Martinez *et al.*, 2012), India (Muthukumar and Prabha, 2012, 2013; Sarwade *et al.*, 2012), Honduras (Zubek *et al.*, 2010) and Japan (Ogura-Tsujita *et al.*, 2013) have been examined for their mycorrhizal status.

The AM colonization patterns encountered within plant roots have been designated as *Arum*-, *Paris*- or intermediate-types based on the distribution of AM fungal structures. In *Arum*-type, the fungal hyphae spreads in the root cortex intercellulary forming arbuscules on the lateral intracellular hyphal branches (Dickson, 2004). In *Paris*-type, the spread of the fungus within the cortex is intracellular forming hyphal coils within cells. Sometimes these hyphal coils bear rudimentary arbuscules. *Arum*-type is presumed to be formed in roots with high growth rates, and when the root cortex possesses abundant intercellular spaces. In contrast, *Paris*-type is presumed to occur in slow growing roots with limited or no intercellular spaces (Brundrett and Kendrick, 1990). A range of intermediate types exist between typical *Arum*- and *Paris*-types exhibiting the characters of both the types (Dickson, 2004). Determining the morphological structures produced by AM fungi is important because, the AM fungal structures like hyphae (inter-and intra-cellular), vesicles, arbuscules or arbusculate coils, and hyphal coils, have different roles in the symbiosis (Dickson *et al.*, 2007). It has been adequately demonstrated that fungal structures such as arbuscules, hyphal as well as arbusculate coils are involved in nutrient transfers thereby indicating a functional association (Smith and Smith, 2011). In contrast, abundance of intercellular or intracellular linear hyphae and vesicles indicate a carbon cost to the host (Sanders and Fitter, 1992). The AM morphology reported for a sample of limited lycophytes and ferns (10%), indicates the wide spread occurrence of *Paris*-type AM morphology (69%) compared to intermediate-type (28%) (Dickson *et al.*, 2007). In a recent study, Zubek *et al.* (2010) demonstrated the wide spread occurrence of *Paris*-type AM in ferns and lycophytes from Honduras. However, intermediate-type AM morphology was reported in roots of *Lycopodium paniculatum* and *Equisetum bogotense* from temperate forests of Patagonia, Argentina (Fernandez *et al.*, 2008). Muthukumar and Prabha (2013) showed that 93% of the lycophytes and ferns they examined from different habitats in the Eastern and Western Ghats, south India, had intermediate-type AM morphology.

Plant roots including those of lycophytes and ferns are also colonized by fungi with melanised or hyaline, regularly septate hyphae, with or without microsclerotia or moniliform cells (Haselwandter and Read, 1982; Newsham, 1999). These fungi, commonly known as dark septate endophytes, appear to be non-host specific, as they are known to colonize over 600 plant species (Fernandez *et al.*, 2010). Earlier studies have shown the presence of dark septate endophyte (DSE) fungal associations in lycophytes and ferns (Berch and Kendrick, 1982; Cooper, 1976; Fernandez *et al.*, 2008, 2010; Hodson *et al.*, 2009; Iqbal *et al.*, 1981; Kessler *et al.*, 2010a, 2010b; Lehnert *et al.*, 2009;

Muthukumar and Prabha, 2012; 2013). Recent studies suggest that DSE fungi could enhance plant growth and health under controlled conditions (Newsham, 2011). It has been speculated that DSE fungi could aid plants in the use of organic nutrients (Cladwell and Jumpponen, 2003). Further, it has also been proposed that DSE-plant association need not be limited to nutrient acquisition, but could be multifunctional (Mandyam and Jumpponen, 2005). For example, DSE fungi could protect plants against pathogens and herbivores through minimizing the carbon availability in the rhizosphere or through the production of secondary metabolites (Mandyam and Jumpponen, 2005). It is therefore essential to assess plants for DSE fungal associations.

Approximately 900–1000 species of lycophytes and ferns are distributed in the Indian Himalayas and the Eastern and Western Ghats. Of these around 270 species of lycophytes and ferns occur in south India (Dixit, 1984). In general, reports of AM fungal status and morphology in Indian lycophytes and ferns are very limited (see Muthukumar and Prabha, 2013 and references therein). The Eastern Ghats are isolated hill ranges occurring in peninsular India that spread over the three Indian states of Orissa, Andhra Pradesh, and Tamil Nadu. The Kolli Hills are among the eight that occur in the southern region of the Eastern Ghats. Assessments of the floristic diversity of the Kolli Hills suggest this hill range has a high degree of endemism and is one of the major reservoirs of medicinal plants in south India (Arun *et al.*, 2002; Gowrisankar *et al.*, 2011; Jayakumar *et al.*, 2002). The Kolli Hills have been subject to anthropogenic pressure ever since humans started to settle on these hills ranges over 600 years ago (Arun *et al.*, 2002). However, the magnitude of disturbance has increased several fold over the years, and includes disturbance from mining, establishment of farm lands and exotic plantations, shifting cultivation, over grazing, fire wood collection and tourism development (Mohanraj *et al.*, 2010; Sundaram and Parthasarathy, 2002). These human activities have resulted in large scale habitat destruction and substantially altered the vegetation and carbon stock (Jayakumar *et al.*, 2002; Mohanraj *et al.*, 2010).

Floristic analyses of Kolli Hills are mostly concerned with the ethnobotanical or medicinal uses of angiosperms, and information is meager for other plant groups (Arokiyaraj *et al.*, 2007; Francis Xavier *et al.*, 2011). Although, Gowrishankar *et al.* (2011) reported the presence of around 80 species of lycophytes and ferns in their floristic survey of the Kolli hills, there is no report on the root fungal associations of plants from this region. This prompted us to assess the AM and DSE fungal status of lycophytes and ferns of the Kolli Hills. Further, we also analysed AM colonization patterns and AM fungal diversity associated with these plant taxa. This information will improve our knowledge and understanding on the distribution and abundance of root fungal associations in lycophytes and ferns in this fragile ecosystem.

Materials and Methods

Study sites and sampling.—The Kolli Hills lies at a longitude of 78° 20′ to 78° 30′E and a latitude of 11° 10′ to 11° 30′N with elevations ranging from 200

TABLE 1. Arbuscular mycorrhizal (AM) and dark septate endophyte (DSE) fungal association and AM morphology along with the previous reports for lycophytes and ferns examined from the Kolli Hills.

Family/Plant species	ST/EI[a]	Site[b]	Habitat[c]	AM status[d]	AM type[e]	Previous reports[f]	
						AM status	AM type
Adiantaceae							
Adiantum hispidulum Sw.		A	TE	AM,DSE*	I	AM [3,13], NM [7]	I[13]
		B	TE	AM,DSE	I		
		C	TE	AM,DSE	I		
Adiantum capillus Junonis Rupr.	M	A	TE	AM*	I*	NR	NR
		B	TE	AM	I		
		C	TE	AM	I		
Adiantum incisum C.Presl	M	A	TE	AM,DSE*	I	AM[8,13]	I[13]
		B	TE	AM,DSE	I		
		C	TE	AM,DSE	I		
Adiantum raddianum C.Presl		A	TE	AM,DSE*	I	AM[13]	I[13]
		B	TE	AM,DSE	P		
		C	TE	AM,DSE	I		
Cheilanthes farinosa (Forssk.) Kaulf.		A	SX	AM,DSE*	I*	AM[8]	NR
		B	SX	AM,DSE	I		
		C	SX	AM,DSE	P		
Cheilanthes tenuifolia (Burm.) Sw.	M	A	SX	AM*,DSE*	I*	NR	NR
		B	TE	AM,DSE	I		
		C	TE	AM,DSE	I		
Cheilanthes opposita Kaulf.		A	TE	AM*,DSE*	P*	NR	NR
		B	EP	AM,DSE	I		
		C	EP	AM,DSE	I		
Doryopteris concolor (Langsd. & Fisch.) Kuhn		A	TE	AM*,DSE*	I*	NR	NR
		B	TE	AM,DSE	I		
		C	TE	AM	I		
Hemionitis arifolia (Burm.) T. Moore.	M	A	TE	AM,DSE*	I*	AM[14,18]	NR
		B	TE	AM,DSE	I		
		C	TE	AM,DSE	I		

TABLE 1. Continued.

Family/Plant species	ST/EI[a]	Site[b]	Habitat[c]	AM status[d]	AM type[e]	Previous reports[f]	
						AM status	AM type
Pityrogramma calomelanos (L.) Link	M	A	TE	AM,DSE	I	AM[10,13,14,18], DSE[13]	I[13]
		B	TE	AM,DSE	I		
		C	TE	AM,DSE	I		
Angiopteridaceae							
		B	TE	AM,DSE	I		
		C	TE	AM,DSE	I		
Aspleniaceae							
Asplenium indicum Sledge	NT	A	TE	AM*,DSE*	I*	NR	NR
		B	TE	AM,DSE	I		
		C	TE	AM,DSE	I		
Asplenium lanceolatum Peter		A	SX	AM*,DSE*	I*	NR	NR
		B	EP	AM,DSE	I		
		C	SX	AM,DSE	P		
Asplenium tenuifolium D.Don		A	TE	AM*,DSE*	I*	NR	NR
		B	TE	AM,DSE	I		
		C	TE	AM,DSE	I		
Azollaceae							
Azolla pinnata R.Br.		A	AQ	NM	—	NM[14]	NR
		C	AQ	NM	—		
Blechnaceae							
Blechnum occidentale L.		A	TE	AM	I*	AM[7]	NR
		B	TE	AM	I		
		C	TE	AM	I		
Cyatheaceae							
Cyathea gigantea (Wall. ex Hook.) Holttum		A	TE	AM*,DSE*	I*	NR	NR
		B	TE	AM,DSE	I		
		C	TE	AM,DSE	I		

TABLE 1. Continued.

Family/Plant species	ST/EI[a]	Site[b]	Habitat[c]	AM status[d]	AM type[e]	Previous reports[f]	
						AM status	AM type
Dennstaedtiaceae							
Microlepia platyphylla (Don) J.Sm.		A	TE	AM	I*	AM[14], NM[22]	NR
		B	TE	AM	I		
Pteridium aquilinum (L.) Kuhn	M	B	TE	AM	I	AM[1,3,4,12,13,14,18,20,21], DSE[9]	I[13], P[4]
		C	TE	AM	I		
Dryopteridaceae							
Arachniodes amabilis (Blume) Tind.		A	TE	AM*,DSE*	I*	NR	NR
		B	TE	AM	I		
		C	TE	AM	I		
Tectaria coadunata (Wall.ex Hainas) Raiz. & Chowd.	M	A	TE	AM,DSE*	I*	AM[18], NM[22]	NR
		B	TE	AM,DSE	I		
Gleicheniaceae							
Dicranopteris linearis (Burm.f.) Underw.	ATR/M	A	TE	AM	I	AM[7,13,14,20], DSE[13]	I[13]
		B	TE	AM	I		
		C	TE	AM	I		
Lindsaeaceae							
Sphenomeris chinensis (L.) J.Sm.		A	TE	AM,DSE	I	AM[7,13], DSE[13]	I[13]
		B	TE	AM,DSE	I		
		C	TE	AM	I		
Lycopodiaceae							
Lycopodium cernuum L.	R/M	A	TE	AM	P*	AM[5,7], DSE[9]	NR
		B	TE	AM	P		
Marattiaceae							
Angiopteris evecta (G.Forst.) Hoffm.	M/ATR	A	TE	AM,DSE	I	AM[7,13,18,20], DSE[13]	I[13]
		B	TE	AM,DSE	I		
		C	TE	AM,DSE	I		

TABLE 1. Continued.

Family/Plant species	ST/EI[a]	Site[b]	Habitat[c]	AM status[d]	AM type[e]	Previous reports[f] AM status	Previous reports[f] AM type
Marsileaceae							
Marsilea minuta L.	M	A	MS	AM,DSE	P*	AM[7,13,18,20], NM[13]	NR
		B	MS	AM,DSE	P		
		C	MS	AM,DSE	P		
Marsilea quadrifolia L.	M	A	MS	AM,DSE	P*	AM[16], NM[13,17]	NR
		B	MS	AM,DSE	P		
Oleandraceae							
Nephrolepis auriculata (L.) Trimen	R/M	A	TE	AM*,DSE*	I*	NR	NR
		B	TE	AM,DSE	I		
Nephrolepis multiflora (Roxb). Jarrett ex Mort.		A	TE	AM,DSE*	P*	AM[7]	NR
		B	TE	AM	I		
		C	TE	AM,DSE	I		
Parkeriaceae							
Ceratopteris thalictroides (L.) Brongn.		A	TE	AM	I*	AM[7,11]	NR
		B	TE	AM,DSE*	I		
		C	TE	AM	I		
Polypodiaceae							
Drynaria quercifolia (L.) J.Sm.	ATR	B	TE	AM,DSE*	P	AM[13,18], NM[14]	I[13]
		C	TE	AM,DSE	I		
Lepisorus nudus Ching		A	TE	AM,DSE*	P*	AM[18]	NR
		B	EP	AM,DSE	P		
		C	EP	AM,DSE	P		
Leptochilus decurrens Blume	ATR	A	TE	AM*,DSE*	P*	NR	NR
		C	TE	AM,DSE	P		
Pyrrosia lanceolata (L.) Farw.	M	A	EP	AM*,DSE*	I*	NR	NR
		B	EP	AM,DSE	I		
		C	TE	AM,DSE	I		

TABLE 1. Continued.

Family/Plant species	ST/EI[a]	Site[b]	Habitat[c]	AM status[d]	AM type[e]	Previous reports[f] AM status	Previous reports[f] AM type
Pteridaceae							
Pteris biaurita L.	M	A	TE	AM,DSE*	I*	AM[12]	NR
		B	TE	AM,DSE	I		
		C	TE	AM,DSE	I		
Pteris pellucida Baher	ATR/M	A	TE	AM,DSE	I	AM[13], DSE[13]	I[13]
		B	TE	AM,DSE	I		
		C	TE	AM,DSE	I		
Schizaeaceae							
Lygodium microphyllum Link	M	A	TE	AM*	I*	NR	NR
		B	TE	AM,DSE*	I		
		C	TE	AM	I		
Selaginellaceae							
Selaginella sp.		A	TE	AM	I	NR	NR
		C	TE	AM	I		
Selaginella wightii Hieron.		A	TE	AM*	I*	NR	NR
		B	TE	AM	I		
		C	TE	AM	I		
Thelypteridaceae							
Christella dentata (Forssk.) Brown. & Jermy		A	TE	AM	P	AM[10,13,14,15]	I[13]
		B	TE	AM	I		
		C	TE	AM	I		
Christella parasitica (L.) H. Lev.	M	A	TE	AM,DSE*	I	AM[13,19]	I[13]
		B	TE	AM	I		
		C	TE	AM,DSE	I		
Macrothelypteris torresiana (Gaudich.) Ching		A	TE	AM,DSE*	I*	AM[22]	NR
		B	TE	AM,DSE	I		
		C	TE	AM,DSE	I		

TABLE 1. Continued.

Family/Plant species	ST/EI[a]	Site[b]	Habitat[c]	AM status[d]	AM type[e]	Previous reports[f]	
						AM status	AM type
Pseudocyclosorus xylodes (Kunze) Ching	EN	A	TE	AM*	I*	NR	NR
		B	TE	AM	I		
		C	TE	AM	I		
Pseudocyclosorus ochthodes (Kunze) Holttum		A	TE	AM,DSE*	I*	AM[14,18]	NR
		B	TE	AM,DSE	I		
		C	TE	AM	I		
Sphaerostephanos arbuscula (Willd.) Holttum		A	TE	AM*	I*	NR	NR
		B	TE	AM	I		
		C	TE	AM	I		
Vittariaceae							
Vittaria elongata Sw.	M	A	EP	AM,DSE*	I*	AM[6,7,14]	NR
		B	EP	AM,DSE	I		
Woodsiaceae							
Diplazium sylvaticum (Bory) Sw.	R	A	TE	AM*,DSE*	I*	NR	NR
		B	TE	AM,DSE	I		
		C	TE	AM,DSE	I		
Diplazium polypodioides Blume		A	TE	AM,DSE	I*	AM[8], DSE[9]	NR
		B	TE	AM,DSE	I		
		C	TE	AM,DSE	I		

* First report of AM-type, AM and DSE association.
[a] ST/EI, Status/economic importance. ATR, at risk; EN, endemic; NT, near threatened; R, rare. M, medicinal.
[b] A, Solakkadu; B, Kuzhivalavu shola; C, Nachiyarkovil.
[c] TE, Terricolous; SX, Saxicolous; EP, epiphyte; AQ, Aquatic; MS, Marshy habitat.
[d] AM, Arbuscular mycorrhizal; DSE, Dark septate endophytic fungi; NM, non-mycorrhizal.
[e] P, *Paris*-type; I, Intermediate- type.
[f] NR no report, [1] Berch and Kendrick (1982), [2] Bhat and Kaveriappa (2003), [3] Cooper (1976), [4] Dickson *et al.* (2007), [5] Duckett and Lignore (1992), [6] Gemma and Koske (1995), [7] Gemma *et al.* (1992), [8] Iqbal et al. (1981), [9] Jumpponen and Trappe (1998), [10] Khade and Rodrigues (2002), [11] Lee *et al.* (2001), [12] Mishra *et al.* (1980), [13] Muthukumar and Prabha (2012), [14] Muthukumar and Udaiyan (2000), [15] Prashar *et al.* (2005), [16] Radhika and Rodrigues (2007), [17] Raghupathy and Mahadevan (1993), [18] Raja *et al.* (1995), [19] Suseela and Devi (1998), [20] Wang and Qiu (2006), [21] Zhang *et al.* (2004), [22] Zhao (2000).

to 1415 m a.s.l. (Mohanraj *et al.*, 2010). Annual rainfall ranges between 300 and 2000 mm, and soil type varies from black to red clay. The vegetation types in the Kolli Hills include evergreen forests, shola forests, deciduous forests, mixed open forest, open scrub and plantation forests (Chittibabu and Parthasarathy, 2000; Mohanraj *et al.*, 2010; Sundaram and Parthasarathy, 2002).

Root and substrate samples of 390, lycophyte and fern sporophytes were collected between December 2011 and March 2012 from Sollakadu (longitude, 78° 20′51.0″ E; latitude, 11°18′11°30″ N, 1197 m a.s. l.) (hereafter referred to as Site-A), Kuzhilivalavu (longitude, 78°21′39.3″ E, latitude of 11°19′51.9″ N, 1237 m a.s.l.)(hereafter referred to as Site-B) and Nachiyar kovil (longitude, 78°20′53.5″ E, latitude of 11°19′4.0″ N) (hereafter referred to as Site-C) in the Kolli Hills of Eastern Ghats. The vegetation type was evergreen forest at Site-A and shola forests at Sites-B and -C. The samples collected represented 47 taxa from 33 genera in 21 families (Table 1). Three sporophytes were sampled for each species. Among the 47 taxa, one could not be identified to species level. The majority of the lycophytes and ferns (79%, 37 of 47 species) sampled were terrestrial, whereas, three species (*Cheilanthes opposita*, Adiantaceae; *Lepisorus nudus* and *Pyrrosia lanceolata*, Polypodiaceae) were found as both terrestrial and epiphytic at different sites. Similarly, *Cheilanthes tenuifolia* (Adiantaceae) was terrestrial or saxicolous, and *Asplenium lanceolatum* (Aspleniaceae) was saxicolous or epiphytic at different sites. The two *Marsilea* species existed in marshy habitat, and *Azolla pinnata* (Azollaceae) occurred as a free floating hydrophyte. *Vittaria elongata* (Vittariaceae) and *Chelianthes farinosa* (Adiantaceae) were epiphytic and saxicolous, respectively. In all, 6 aquatic, 15 marshy, 27 epiphytic, 18 saxicolous and 324 terrestrial individuals were examined from the three sites (Table 1). Plants were carefully removed and the roots were rinsed with water to remove the adhering litter and soil particles. The roots were preserved in FAA (formaldehyde/acetic acid/70% ethanol, 5V:5V:90V) until processing. Substrates shaken from the roots and adjacent to the roots were collected. Substrate associated with fern roots was very limited, even for terrestrial species, due to the superficial presence of roots and the very shallow soil profile. For epiphytic and saxicolous taxa, the substrate was a very thin layer over the tree trunk or rock surface. Therefore, soil and substrate samples of all the individuals collected from a site were bulked to form a composite substrate sample. The composite substrate samples were air dried, packed in polythene bags and stored at 4°C for AM fungal spore isolation. This composite sample was used for determining soil chemistry and the isolation of AM fungal spores.

Determination of soil characteristics.—The pH and electrical conductivity (EC) of the soil samples was determined electrometrically by using digital electronic meters (ELICO, India) in a 1:1 (soil: deionised water) suspension. Total N and available P were determined according to Jackson (1971) and exchangeable potassium (K) was determined after extraction with ammonium acetate (Jackson, 1971).

Root-fungal assessment.—The fixed roots were cut into 1-cm sections, cleared in 2.5% KOH at 90 °C (Koske and Gemma, 1989), acidified with 5N HCl and stained with trypan blue or chlorazol Black E (0.05% in lacto glycerol). Generally, fern roots remained dark after clearing and were bleached in alkaline H_2O_2 prior to acidification. The roots were stained overnight in the staining solution. The stained roots were examined with an Olympus BX51 compound microscope (×400) for the presence of AM fungal structures and the percentage of root length colonization was estimated according to the magnified intersection method (McGonigle *et al.*, 1990). In addition, the number of AM fungal structure intersections was also individually noted. It was thus possible to quantify both the root length colonized by AM fungal structures and the total root length colonized. Only root specimens possessing arbuscules or arbusculated coils were considered to be AM. The roots were also scored for total root length colonized by DSE fungal structures and total root length colonized as described above based on the presence of characteristic hyaline or melanised regularly-septate hyphae and when present, microsclerotia or moniliform cells (Peterson *et al.*, 2008). Sometimes the microsclerotia or moniliform cells were associated with a limited amount of intracellular hyphae.

The AM morphology was classified as *Paris*- or intermediate-types based on whether the fungal hyphae were linear and inter- or intracellular within the cells as coils. In this study, absence of inter or intracellular linear hyphae and limited arbuscular development on hyphal coils were used to designate *Paris*-type AM. Images of colonization and fungal structures were captured with a ProgRes®C3 digital camera.

Isolation and identification of AM fungal spores.—The substrate samples were screened for the presence of AM fungal spores according to Muthukumar and Udaiyan (2000). As AM fungal spores were either absent in most of the substrate samples or were present as spore cases, we did not enumerate them. When intact AM fungal spores or sporocarps (non-collapsed spores with cytoplasmic contents and free from parasitic attack) were present, they were transferred using a wet needle and mounted in polyvinyl alcohol-lactoglycerol with or without Melzer's reagent on a glass slide for identification (Schenck and Perez, 1990). Spores were identified from spore morphology and sub-cellular characters and compared to the original descriptions at Schüβlers lab web page (www.Irz-muenchen.de/-schuessler/amphylo/amphylo_species.html) and the culture database established by INVAM (http://www.invam.caf.wvu.edu). The spellings of scientific names are as suggested by Schüβler and Walker (2010).

Plant nomenclature, life-forms, status and economic importance.—Nomenclature and authorities for lycophytes and ferns are as used by Manickam (1996) and Irudayaraj and Manickam (2003). Life-forms were assigned as per field observation. The status (Chandra *et al.*, 2008; Maridass and Raju, 2010) and economic importance (Britto *et al.*, 2012; Mannar Mannan *et al.*, 2008; Maridass and Raju, 2010; Pathak *et al.*, 2011; Perumal, 2010) of the lycophytes and ferns were determined from the literature.

Statistical analysis.—Data on soil factors were subjected to analysis of variance (ANOVA) to assess if any significant variations occurred in the soil characteristics of different sites. The influence of plant species and sites on the extent of AM and DSE colonization and root length with different structures were analysed using Kruskal-Wallis non-parametric test as the data of fungal variables failed to satisfy normality even after transformation (Zar, 1984). Post-hoc comparisons were made using Mann-Whitney *U*-test. As both AM and DSE fungi occupy the same niche, the relation between these fungal variables was examined using Pearson's correlation to determine the nature of interaction.

Results

Soil characteristics.—The sandy loam (Site-A) and clay loam (Sites-B and C) soils were slightly alkaline with pH ranging from 7.9 to 8.1. Electrical conductivity ranged from 0.06 to 0.07 mS cm^{-1}. Total N ranged from 10.3 mg kg^{-1} (Site-A and -C) to 10.4 mg kg^{-1} (Site-B). Total P ranged between 0.6 mg kg^{-1} (Site-A) and 0.7 mg kg^{-1} (Sites-B and -C), and exchangeable K ranged from 17.4 (Site-A) to 18.2 mg kg^{-1} (Site-C). The variations in soil characters among sites (pH-$F_{2,8}$=0.826; EC-$F_{2,8}$=0.273; N-$F_{2,8}$=0.125; P-$F_{2,8}$=0.500; K-$F_{2,8}$=0.164) were not significant ($p>0.05$).

Occurrence of AM fungal associations.—Among the 47 lycophytes and fern species (belonging to 21 families and 33 genera from the three different sites) examined, 46 had AM fungal associations (Table 1). The aquatic fern *A. pinnata* lacked AM fungal structures. The entry of fungi into roots was either directly though the rhizodermis after the formation of a swollen appressorium at the entry point, or through the root hairs (Fig. 1 a,b). Intraradical hyphae were broad, aseptate, intracellular, smooth or with knob-like projections (Fig. 1 h) or had inflated areas with a beaded appearance (Fig. 1 g), and were linear or coiled (Fig. 1 c,d). Arbuscules borne on intracellular hyphae or hyphal coils (Fig. 1 c,d,f) were very limited to elaborate, sometimes lamp brush-like (Fig. 1 i). Vesicles were intracellular (Fig. 1 e), but were absent in mycorrhizal roots of *P. lanceolata.*

Distribution of AM morphological types.—The majority (72%, 34/47) of the mycorrhizal lycophytes and ferns had features that were typical of intermediate-type morphology (Table 1). However, seven plant species (15%) exhibited both *Paris*- and intermediate-type AM morphologies. Typical *Paris*-type was characterized by the absence of inter- or intracellular linear hyphae and the presence of intracellular hyphal coils or arbusculate coils with reduced arbuscular proliferation and intracellular vesicles. Such typical *Paris*-type AM was observed in one lycophyte (*Lycopodium cernuum*, Lycopodiaceae) and four fern species (*L. nudus*, *Leptochilus decurrens*, Polypodiaceae; *Marsilea minuta* and *Marsilea quadrifolia*, Marsileaceae) (Table 1, Fig. 1. a).

Extent of AM fungal colonization.—The extent of AM fungal colonization and root length colonized by AM fungal structures varied significantly with plant species. The average percentage of root length with total AM colonization

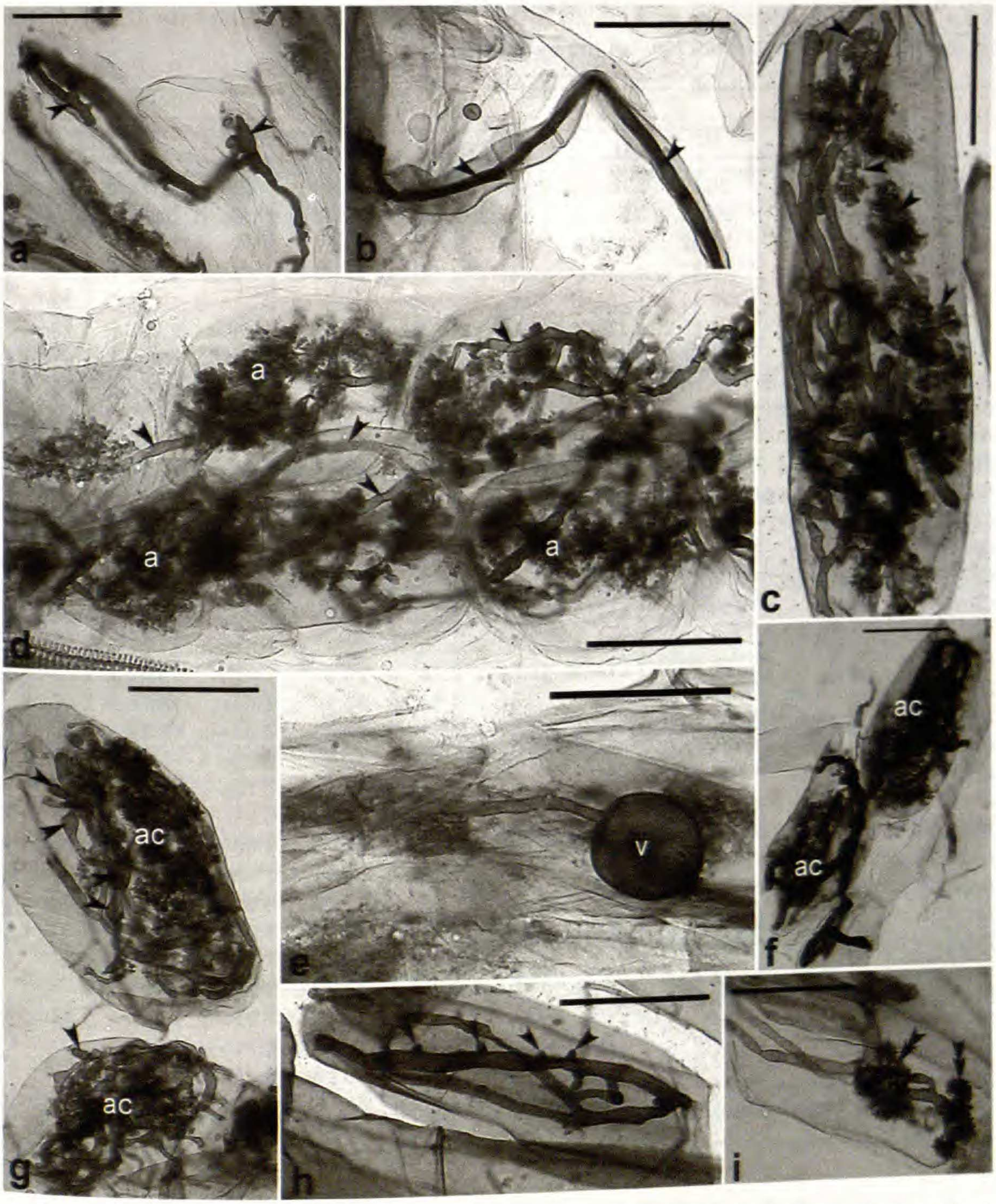

FIG. 1. a–c: Arbuscular mycorrhizal colonization in ferns of the Kolli Hills. a. Appressorium (arrow heads) and hyphal entry into roots though the rhizodermis in *Pyrrosia lanceolata*, b. Hyphal entry (arrow heads) through root hair in *Doryopteris concolor*. c. Arbusculate coil in root cells of *Lepisorus nudus* with reduced arbuscules (arrow heads). d. Intracellular hyphae (arrow heads) and arbuscules in *Adiantum incisum* e. Intracellular vesicle (v) in *Pseudocyclosorus xylodes*. f. Arbusculate coils (ac) in *Blechnum occidentale*. g. Arbusculate coils (ac) with beaded hyphae (arrow heads) in *Leptochilus decurrens*. h. Intracellular hyphal coil in *Drynaria quercifolia* with knob-like hyphal projections (arrow heads); i. Lamp-brush like arbuscules (double arrow heads) in *Diplazium sylvaticum*. Scale bars=50 μm.

TABLE 2. Average arbuscular mycorrhizal (AM) and dark septate endophyte (DSE) fungal colonization in lycophytes and ferns of the Kolli Hills.

Plant species	AM colonization#			
	%RLH	%RLV	%RLAC	%RLHC
Adiantum capillus	20.53 ± 1.32d–k☆	23.03 ± 2.39a–e	14.92 ± 3.29i–n	22.76 ± 2.45g–n
Adiantum hispidulum	20.21 ± 3.24d–k	11.23 ± 1.69h–o	28.30 ± 3.06a–d	20.57 ± 2.89i–p
Adiantum incisum	31.02 ± 2.16abc	9.44 ± 1.85i–q	28.51 ± 3.08a–d	7.97 ± 1.29q–t
Adiantum raddianum	15.81 ± 4.11i–l	12.00 ± 2.44h–n	2.71 ± 1.36qr	51.65 ± 4.56a
Angiopteris evecta	26.14 ± 2.25a–h	18.00 ± 1.99b–i	28.66 ± 2.36a–d	10.38 ± 1.72o–t
Arachniodes amabilis	28.60 ± 3.21a–e	10.80 ± 2.75h–p	13.59 ± 2.05j–o	25.62 ± 5.13g–l
Asplenium indicum	23.78 ± 2.04a–j	7.49 ± 0.94k–r	36.18 ± 2.54a	15.40 ± 1.87l–s
Asplenium lanceolatum	20.30 ± 5.22d–k	11.86 ± 2.41h–n	16.18 ± 3.23h–m	28.41 ± 4.15f–k
Asplenium tenuifolium	31.85 ± 2.58ab	15.22 ± 4.49e–l	5.92 ± 3.05o–r	21.39 ± 1.35h–o
Azolla pinnata	0.00 ± 0.00m	0.00 ± 0.00r	0.00 ± 0.00r	0.00 ± 0.00t
Blechnum occidentale	27.83 ± 1.53a–f	14.15 ± 3.57f–l	31.30 ± 4.34a–c	3.99 ± 1.13st
Ceratopteris thalictroides	18.83 ± 1.81e–k	11.48 ± 1.74h–n	34.80 ± 3.58ab	14.59 ± 4.64l–s
Cheilanthes farinosa	15.98 ± 5.85i–l	16.34 ± 2.79d–k	8.80 ± 3.44m–q	22.99 ± 5.28g–m
Cheilanthes opposita	15.47 ± 4.13j–l	24.90 ± 2.23a–d	8.84 ± 0.94m–q	31.95 ± 5.18d–i
Cheilanthes tenuifolia	16.51 ± 3.06h–k	16.68 ± 1.74d–j	17.14 ± 1.84h–m	29.68 ± 2.39d–j
Christella dentata	13.88 ± 3.57kl	21.36 ± 2.61b–g	15.21 ± 1.63h–n	29.23 ± 3.76e–k
Christella parasitica	23.20 ± 2.71a–k	8.03 ± 1.86j–r	22.97 ± 2.91c–i	21.27 ± 3.91h–o
Cyathea gigantea	29.16 ± 2.11a–d	10.50 ± 2.98i–p	26.32 ± 1.87b–f	16.39 ± 2.01l–r
Dicranopteris linearis	27.57 ± 1.50a–f	2.15 ± 0.94pqr	36.16 ± 2.53a	16.06 ± 2.02l–r
Diplazium polypodioides	27.14 ± 1.98a–g	17.97 ± 1.31b–i	27.83 ± 2.24a–e	8.10 ± 2.23q–t
Diplazium sylvaticum	28.46 ± 3.43a–e	25.60 ± 2.15a–c	19.33 ± 3.22e–k	6.36 ± 1.74r–t
Doryopteris concolor	30.76 ± 1.33abc	15.53 ± 3.44e–k	30.40 ± 2.78a–c	6.86 ± 1.18r–t
Drynaria quercifolia	22.17 ± 7.08b–k	2.56 ± 2.01o–r	0.23 ± 0.23r	37.42 ± 12.44c–f
Hemionitis arifolia	22.10 ± 1.89b–k	23.19 ± 1.71a–e	26.64 ± 2.86b–f	9.20 ± 3.05p–t
Lepisorus nudus	0.67 ± 0.33m	3.23 ± 1.49n–r	8.97 ± 0.53m–q	45.02 ± 4.03a–c
Leptochilus decurrens	2.36 ± 1.09m	24.97 ± 2.17a–d	13.12 ± 4.89j–o	40.20 ± 5.09b–e
Lycodium microphyllum	21.50 ± 1.99c–k	8.71 ± 1.94j–r	36.05 ± 3.20a	16.26 ± 3.55l–r
Lycopodium cernuum	1.98 ± 0.92m	6.23 ± 1.71l–r	6.91 ± 1.01n–r	51.66 ± 3.57a
Macrothelypteris torresiana	25.45 ± 2.88a–i	13.62 ± 3.20f–l	18.92 ± 2.74f–l	25.29 ± 3.73g–l
Marsilea minuta	0.00 ± 0.00m	22.38 ± 5.92a–f	5.31 ± 1.39o–r	29.70 ± 5.52d–j
Marsilea quadrifolia	0.00 ± 0.00m	1.38 ± 0.71qr	5.35 ± 0.71o–r	12.50 ± 2.06m–s
Microlepia platyphylla	15.50 ± 3.21a–k	9.10 ± 1.02g–m	20.98 ± 0.41a–d	14.24 ± 1.87l–r
Nephrolepis auriculata	26.10 ± 0.91a–h	14.04 ± 3.97f–l	30.68 ± 3.19a–c	8.82 ± 1.15p–t
Nephrolepis multiflora	5.29 ± 1.40m	3.72 ± 2.61m–r	16.33 ± 3.57h–m	50.59 ± 2.64ab
Pityrogramma calomelanos	21.31 ± 3.24c–k	19.87 ± 2.50b–h	25.94 ± 0.72c–g	10.79 ± 2.76n–t
Pseudocyclosorus ochthodes	7.53 ± 0.79lm	30.61 ± 2.70a	3.33 ± 2.21p–r	40.94 ± 2.96a–d
Pseudocyclosorus xylodes	24.23 ± 3.41a–j	26.02 ± 3.46a–c	2.60 ± 1.04qr	17.57 ± 3.18k–r
Pteridium aquilinum	25.26 ± 2.21a–i	10.92 ± 0.94h–p	11.57 ± 1.75k–p	33.83 ± 1.61d–g
Pteris biaurita	22.83 ± 1.49a–k	18.07 ± 2.47b–i	20.23 ± 2.10d–k	21.19 ± 1.59h–o
Pteris pellucida	22.51 ± 1.64a–k	17.92 ± 2.18b–i	21.27 ± 2.19d–j	19.04 ± 2.32j–q
Pyrrosia lanceolata	27.82 ± 3.32a–f	0.00 ± 0.00r	0.00 ± 0.00r	32.98 ± 2.40d–h
Selaginella sp.	18.36 ± 3.00f–k	0.17 ± 0.17r	10.59 ± 0.81l–q	46.88 ± 3.42a–c
Selaginella wightii	27.01 ± 1.99a–g	10.48 ± 2.59i–p	20.00 ± 0.88d–k	14.91 ± 4.55l–s
Sphaerostephanos arbuscula	21.28 ± 1.72c–k	26.09 ± 3.00ab	18.24 ± 2.25f–l	17.65 ± 2.40k–r
Sphenomeris chinensis	29.35 ± 2.44a–d	14.09 ± 2.32f–l	18.08 ± 1.71f–l	22.65 ± 1.94g–n
Tectaria coadunata	17.41 ± 1.52g–k	17.16 ± 3.49c–j	23.74 ± 4.20c–h	21.78 ± 1.03h–o
Vittaria elongata	32.25 ± 2.09a	13.50 ± 2.03f–l	17.68 ± 4.10g–l	7.13 ± 1.69q–t

TABLE 2. Extended.

AM colonization[#]	DSE colonization[##]			
%RLTC	%RLDSH	%RLMO	%RLMS	%RLDTC
81.24 ± 1.00a–c	0.00 ± 0.00g	0.00 ± 0.00d	0.00 ± 0.00f	0.00 ± 0.00h
80.32 ± 2.84a–c	0.31 ± 0.21fg	4.53 ± 2.56a	0.00 ± 0.00f	4.84 ± 2.52e–h
76.94 ± 2.01a–d	0.14 ± 0.14g	0.00 ± 0.00d	3.26 ± 1.15d–f	3.40 ± 1.26f–h
82.17 ± 1.19ab	0.34 ± 0.23fg	0.30 ± 0.30cd	0.00 ± 0.00f	0.64 ± 0.34gh
83.18 ± 1.05ab	1.34 ± 0.50d–g	0.22 ± 0.22cd	0.00 ± 0.00f	1.56 ± 0.66f–h
78.62 ± 2.97a–d	0.44 ± 0.29fg	0.00 ± 0.00d	0.00 ± 0.00f	0.44 ± 0.29gh
82.85 ± 1.35ab	1.99 ± 0.83d–g	0.00 ± 0.00d	0.00 ± 0.00f	1.99 ± 0.83f–h
76.75 ± 2.80a–d	5.60 ± 1.04bc	0.22 ± 0.22cd	6.13 ± 1.90cd	11.96 ± 1.76cd
74.38 ± 3.90b–e	4.00 ± 1.36b–e	1.20 ± 0.98b–d	5.13 ± 2.15c–e	10.34 ± 3.57c–e
0.00 ± 0.00k	0.00 ± 0.00g	0.00 ± 0.00d	0.00 ± 0.00f	0.00 ± 0.00h
77.27 ± 2.79a–d	0.00 ± 0.00g	0.00 ± 0.00d	0.00 ± 0.00f	0.00 ± 0.00h
79.69 ± 1.61a–c	0.96 ± 0.66e–g	0.36 ± 0.36b–d	0.00 ± 0.00f	1.33 ± 0.88f–h
64.11 ± 4.61f–h	2.47 ± 0.73d–g	0.00 ± 0.00d	5.00 ± 1.41c–e	7.47 ± 1.85d–f
81.15 ± 1.39a–c	1.91 ± 0.66d–g	0.00 ± 0.00d	0.00 ± 0.00f	1.91 ± 0.66f–h
80.02 ± 0.92a–c	2.12 ± 0.44d–g	0.97 ± 0.34b–d	3.45 ± 0.99d–f	6.63 ± 0.96d–g
79.68 ± 1.56a–c	0.00 ± 0.00g	0.00 ± 0.00d	0.00 ± 0.00f	0.00 ± 0.00h
75.48 ± 4.12a–d	11.95 ± 4.46a	0.00 ± 0.00d	2.06 ± 1.31ef	14.01 ± 5.15c
82.37 ± 1.27ab	5.78 ± 1.19b	0.40 ± 0.27b–d	0.00 ± 0.00f	6.20 ± 1.23e–h
81.95 ± 1.49ab	0.00 ± 0.00g	0.00 ± 0.00d	0.00 ± 0.00f	0.00 ± 0.00h
81.03 ± 1.09a–c	0.64 ± 0.44fg	0.00 ± 0.00d	2.19 ± 0.85d–f	2.83 ± 1.22f–h
79.75 ± 2.59a–c	0.00 ± 0.00g	0.31 ± 0.21cd	0.75 ± 0.53f	1.05 ± 0.64gh
83.55 ± 0.78ab	1.49 ± 1.27d–g	0.00 ± 0.00d	0.00 ± 0.00f	1.49 ± 1.27f–h
62.37 ± 6.55g–i	2.72 ± 0.59c–g	1.95 ± 1.24b	22.73 ± 7.04a	27.40 ± 7.81a
81.13 ± 1.20a–c	0.52 ± 0.27fg	0.00 ± 0.00d	0.00 ± 0.00f	0.52 ± 0.27gh
57.88 ± 4.17hi	4.48 ± 0.93b–d	0.00 ± 0.00d	19.07 ± 1.97b	23.49 ± 2.75ab
80.65 ± 1.01a–c	0.43 ± 0.28fg	3.82 ± 0.63a	0.00 ± 0.00f	4.24 ± 0.86f–h
82.52 ± 0.57ab	0.00 ± 0.00g	0.00 ± 0.00d	0.14 ± 0.14f	0.14 ± 0.14h
66.78 ± 3.86e–g	0.00 ± 0.00g	0.00 ± 0.00d	0.00 ± 0.00f	0.00 ± 0.00h
83.28 ± 0.61ab	0.60 ± 0.60fg	0.82 ± 0.58b–d	0.00 ± 0.00f	1.42 ± 0.76f–h
55.73 ± 5.63i	0.00 ± 0.00g	0.00 ± 0.00d	0.00 ± 0.00f	0.00 ± 0.00h
19.24 ± 2.66j	0.00 ± 0.00g	0.00 ± 0.00d	0.00 ± 0.00f	0.00 ± 0.00h
59.81 ± 0.94a–c	0.00 ± 0.00g	0.00 ± 0.00d	0.00 ± 0.00f	0.00 ± 0.00h
79.63 ± 1.33a–c	2.32 ± 0.59d–g	0.00 ± 0.00d	0.00 ± 0.00f	2.32 ± 0.59f–h
75.93 ± 2.20a–d	0.00 ± 0.00g	0.00 ± 0.00d	2.50 ± 0.93d–f	2.51 ± 0.94f–h
77.91 ± 2.11a–d	0.22 ± 0.22g	0.28 ± 0.28cd	0.91 ± 0.43f	1.41 ± 0.42f–h
82.40 ± 0.91ab	0.13 ± 0.13g	0.14 ± 0.14d	0.00 ± 0.00f	0.27 ± 0.18h
70.42 ± 2.71d–f	0.00 ± 0.00g	0.00 ± 0.00d	0.00 ± 0.00f	0.00 ± 0.00h
81.58 ± 2.31ab	0.00 ± 0.00g	0.00 ± 0.00d	0.00 ± 0.00f	0.00 ± 0.00h
82.32 ± 0.86ab	2.10 ± 0.64d–g	0.13 ± 0.13d	2.01 ± 0.54ef	4.24 ± 1.09f–h
80.73 ± 1.08a–c	0.54 ± 0.31fg	0.11 ± 0.11d	0.00 ± 0.00f	0.64 ± 0.34gh
60.80 ± 2.80g–i	0.79 ± 0.79fg	0.00 ± 0.00d	19.36 ± 3.12ab	20.15 ± 3.06b
75.99 ± 2.21a–d	0.00 ± 0.00g	0.00 ± 0.00d	0.00 ± 0.00f	0.00 ± 0.00h
72.40 ± 4.93c–e	0.00 ± 0.00g	0.00 ± 0.00d	0.00 ± 0.00f	0.00 ± 0.00h
83.26 ± 1.09ab	0.00 ± 0.00g	0.00 ± 0.00d	0.00 ± 0.00f	0.00 ± 0.00h
84.17 ± 0.86a	2.26 ± 1.37d–g	0.00 ± 0.00d	0.00 ± 0.00f	2.26 ± 1.37f–h
80.08 ± 1.92a–c	2.99 ± 1.35b–g	0.00 ± 0.00d	4.41 ± 1.25d–f	7.40 ± 2.49d–f
70.55 ± 3.02d–f	3.61 ± 1.27b–f	1.85 ± 0.51bc	8.69 ± 4.19c	14.14 ± 5.29c

TABLE 2. Continued.

Plant species	AM colonization# %RLH	%RLV	%RLAC	%RLHC
H statistics				
Plant species (PS) (df, 46)	2014.974***	2144.24***	2741.20***	2494.130***
Site (S) (df, 2)	0.5942ns	45.289***	8.4848*	33.192***
PS × S (df, 81)	924.14***	863.58***	500.64***	758.89***

RLH, Root length with hyphae; RLA/AC, Root length with arbuscules/arbusculate coils; RLV, Root length with vesicles; RLC, Root length with hyphal coils; RLTC, Root length with total colonization.
RLDSH, Root length with dark septate fungal hyphae; RLMI/MO, Root length with microsclerotia/ moniliform hyphae; RLDTC, Root length with total colonization.
☆ Means ± S.E in a column followed by same letter(s) are not significantly different.
*,**,***,ns: Significant at $p<0.05$, $p<0.01$, $p<0.001$ and not significant respectively.

ranged from 19.24% (*M. quadrifolia*) to 84.17% (*Sphenomeris chinensis*, Lindsaeaceae) (Table 2). Average percentage root length with total AM colonization for families ranged from 19.74% (Marsileaceae) to 83.18% (Angiopteridaceae). Average percentage root length with total AM colonization of lycophytes in the present study (77.41 ± 4.09%) was slightly higher compared to those of ferns (74.24 ± 2.39%). However, this variation in average percentage root length with total AM colonization between lycophytes and ferns was not significant ($U_{30,360} = 4933$; $p>0.05$). Life-forms differed significantly in average percentage root length with total AM colonization (H_4 =78.261, $p<0.001$). The maximum average percentage root length with total AM colonization occurred in terrestrial taxa (78.81%) and the minimum occurred in ferns from marshy habitats (49.74%) (Fig. 2a). Although the variations in percentage root length with total AM colonization between species was significantly different, the differences between sites were not significant (Table 2, 3). The percentage root length with hyphae varied among taxa and ranged from 0.67% (*L. nudus*) and 32.25% (*Vittaria elongata*, Vittariaceae). The variations in percentage root length with hyphae among sites were significant among species but not among sites (Table 2, 3). There were differences in percentage of root length with hyphal coils both among species and sites. The percentage of root length with hyphal coils ranged from 3.99% (*Blechnum occidentale*, Blechnaceae) to 51.66% (*L. cernuum*, Lycopodiaceae). The variation in percentage root length with hyphal coils among species, sites and species × site interactions were highly significant ($p<0.001$). Percentage of root length with arbusculate coils ranged between <1 (*Drynaria quercifolia*, Polypodiaceae) and 36.18% (*Asplenium indicum*, Aspleniaceae). The differences in percentage root length with hyphal coils among species, sites and species × site interactions were significant ($p<0.001$). The percentage root length with vesicles ranged from <1% (*Selaginella* sp., Selaginellaceae) to 30.61% (*Pseudocyclosorus xylodes*, Thelypteridaceae) and the differences among species, sites and their interactions were highly ($p<0.001$) (Table 2).

TABLE 2. Continued. Extended.

AM colonization[#]	DSE colonization[##]			
%RLTC	%RLDSH	%RLMO	%RLMS	%RLDTC
1708.60***	1576.76***	461.25***	1635.94***	2178.27***
0.2155ns	0.295ns	11.566**	17.319***	6.804*
722.722***	443.756***	162.694***	216.875***	381.759***

Among the two marshy ferns, the percentage root length with total AM fungal colonization of *M. minuta* with more than 55% of its average root length colonized was significantly higher ($U_{6,9}$ = 54.00; $p<0.001$) than that of *M. quadrifolia* (19%).

AM fungal species diversity.—The majority of spores isolated from the substrate samples were devoid of contents, parasitized, or consisted of only spore cases. Nevertheless, nine AM fungal spore morphotypes were distinguished on the basis of spore morphology from the substrate samples examined (Table 4; Fig. 3). These included *Acaulospora foveata* Trappe & Janos, *Acaulospora rehmii* Sieverd & Toro, *Acaulospora scrobiculata* Trappe, *Funneliformis constrictum* (Trappe) C. Walker & Schüßler, *Funneliformis geosporum* (T.H. Nicolson & Gerd.) C. Walker & A. Schüßler, *Glomus microcarpum* Tul. & Tul., *Glomus invermaium* Hall, *Gigaspora decipiens* Hall & Abbott and *Sclerocystis rubiformis* Gerd. & Trappe.

Species richness was maximum in Site-A (8 spore morphotypes) followed by Site-C (7) and Site B (3). *Acaulospora scrobiculata*, *G. microcarpum* and *F. geosporum* occurred in all sites (Table 4).

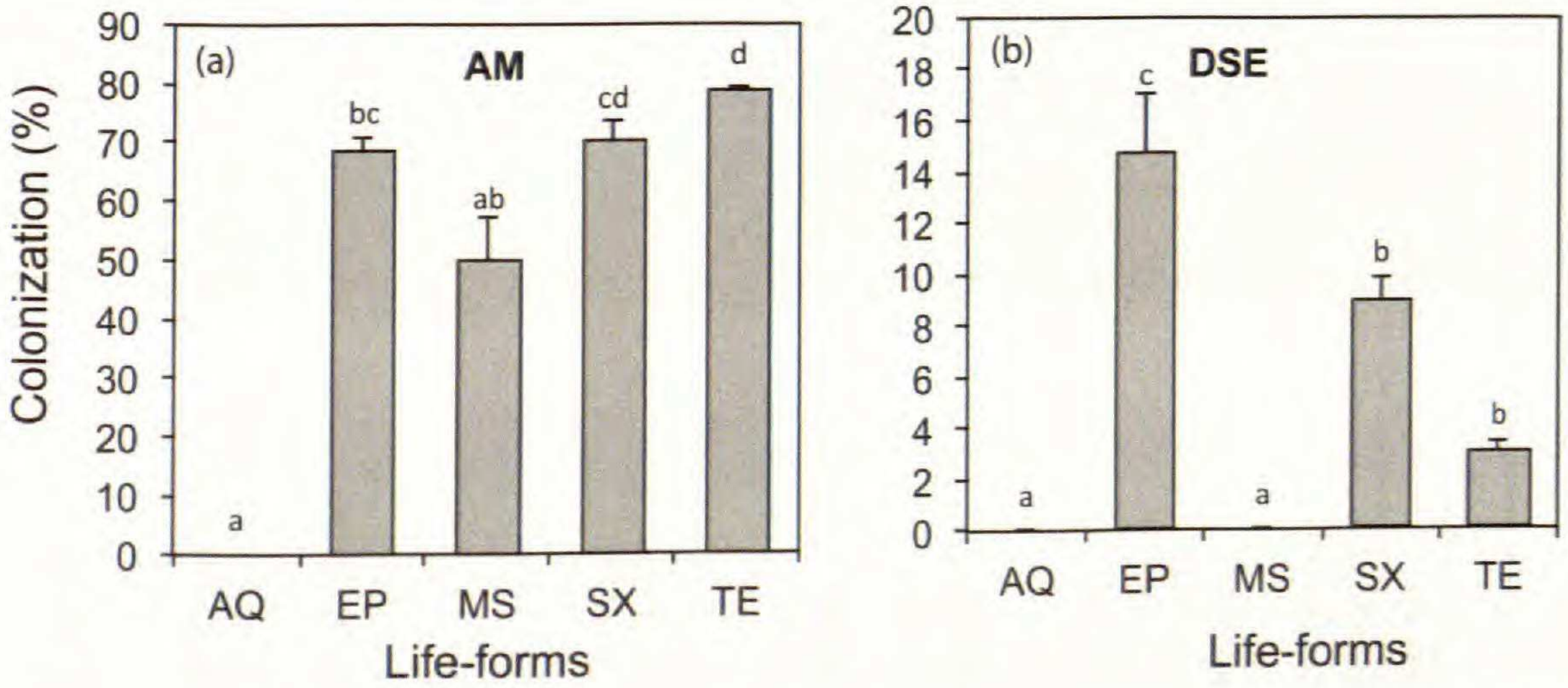

FIG. 2. Average arbuscular mycorrhizal (AM) (a) and dark septate endophyte (DSE) (b) fungal colonization in lycophytes and ferns of aquatic (AQ), epiphytic (EP), marshy (MS), saxicolous (SX) and terrestrial (TE) life-forms. Bars bearing same letter(s) are not significantly different according to DMRT ($p>0.05$).

TABLE 3. Extent of arbuscular mycorrhizal (AM) colonization in lycophytes and ferns at different sites of the Kolli Hills.

Plant species	Site[a]	AM colonization[b]				
		%RLH	%RLV	%RLAC	%RLHC	%RLTC
Adiantum hispidulum	A	18.86 ± 8.49a*	8.80 ± 0.96a	22.75 ± 2.83b	24.09 ± 7.54a	74.50 ± 7.39b
	B	25.98 ± 4.68a	13.18 ± 3.15a	27.01 ± 7.03ab	14.87 ± 4.15a	81.03 ± 3.49ab
	C	15.78 ± 2.21a	11.72 ± 4.27a	35.15 ± 3.89a	22.76 ± 1.13a	85.42 ± 0.36a
Adiantum capillus	A	19.03 ± 1.63a	19.50 ± 4.97a	14.32 ± 5.32a	28.50 ± 2.09a	81.35 ± 2.79a
	B	20.87 ± 1.12a	25.20 ± 5.25a	18.29 ± 9.50a	18.41 ± 5.34a	82.77 ± 0.41a
	C	21.71 ± 3.90a	24.38 ± 2.58a	12.15 ± 1.30a	21.36 ± 3.50a	79.60 ± 1.19a
Adiantum incisum	A	33.24 ± 5.09a	8.20 ± 3.48ab	25.99 ± 6.33ab	6.01 ± 2.48a	73.44 ± 3.27a
	B	30.30 ± 3.87a	13.59 ± 2.00b	23.23 ± 4.74a	7.28 ± 0.57a	74.39 ± 3.08ab
	C	29.52 ± 3.38a	6.52 ± 3.36a	36.32 ± 1.88b	10.62 ± 2.77a	82.98 ± 0.89b
Adiantum raddianum	A	26.47 ± 2.39a	12.40 ± 3.93a	0.00 ± 0.00b	43.13 ± 6.83a	82.00 ± 1.14a
	B	0.00 ± 0.00 b	5.63 ± 1.25a	8.14 ± 1.61a	66.99 ± 5.01a	80.76 ± 3.14a
	C	20.95 ± 1.27a	17.96 ± 4.01a	0.00 ± 0.00b	44.83 ± 3.83a	83.74 ± 1.88a
Angiopteris evecta	A	26.24 ± 1.88b	19.50 ± 4.12ab	26.18 ± 5.18a	10.05 ± 1.58b	81.98 ± 1.88a
	B	19.13 ± 1.92c	21.95 ± 1.27a	27.18 ± 3.96a	16.06 ± 1.19a	84.31 ± 1.97a
	C	33.05 ± 2.24a	12.55 ± 2.27b	32.63 ± 3.53a	5.04 ± 1.14b	83.26 ± 2.13a
Azolla pinnata	A	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
	C	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
Arachniodes amabilis	A	27.97 ± 6.40a	2.23 ± 1.38b	12.84 ± 5.23a	39.59 ± 6.34a	82.62 ± 5.31a
	B	24.51 ± 7.56a	12.27 ± 4.63a	10.93 ± 2.57a	21.93 ± 10.43ab	69.63 ± 3.32b
	C	33.33 ± 2.35a	17.91 ± 2.05a	17.02 ± 2.63a	15.34 ± 3.03b	83.60 ± 2.45a
Asplenium indicum	A	23.67 ± 3.31a	7.25 ± 1.69a	31.62 ± 4.41a	17.39 ± 5.31a	79.93 ± 2.77a
	B	21.62 ± 3.32a	7.79 ± 2.45a	39.81 ± 5.51a	16.74 ± 1.29a	85.96 ± 1.15a
	C	26.05 ± 4.78a	7.41 ± 1.27a	37.12 ± 3.19a	12.08 ± 1.89a	82.66 ± 1.90a
Asplenium lanceolatum	A	31.44 ± 1.10a	11.55 ± 3.40a	18.16 ± 4.18a	20.04 ± 2.05a	81.19 ± 3.23a
	B	29.47 ± 3.96a	15.95 ± 6.15a	15.11 ± 8.88a	21.48 ± 5.06a	82.01 ± 1.01a
	C	0.00 ± 0.00b	8.07 ± 2.17a	15.26 ± 2.77a	43.72 ± 1.74a	67.05 ± 3.39a
Asplenium tenuifolium	A	40.46 ± 1.27a	0.00 ± 0.00b	0.00 ± 0.00b	19.46 ± 3.81a	59.92 ± 4.49b
	B	24.36 ± 3.42b	18.30 ± 6.34a	17.76 ± 2.53a	21.78 ± 1.89a	82.20 ± 1.66a
	C	30.74 ± 0.83ab	27.37 ± 2.74a	0.00 ± 0.00b	22.92 ± 0.87a	81.02 ± 1.45a
Blechnum occidentale	A	26.82 ± 2.59a	13.30 ± 1.18b	34.29 ± 3.18a	5.94 ± 2.96a	80.36 ± 4.91a
	B	25.80 ± 3.65a	26.56 ± 0.70a	17.26 ± 6.82b	4.47 ± 0.97a	74.09 ± 7.54a
	C	30.86 ± 1.01a	2.59 ± 2.59c	42.35 ± 2.24a	1.57 ± 0.83a	77.36 ± 1.67a

TABLE 3. Continued.

Plant species	Site[a]	AM colonization[b]				
		%RLH	%RLV	%RLAC	%RLHC	%RLTC
Ceratopteris thalictroides	A	18.02 ± 3.01a	11.36 ± 2.05a	39.70 ± 4.08a	8.79 ± 2.08b	77.87 ± 1.55a
	B	17.54 ± 3.30a	9.14 ± 4.65a	25.79 ± 8.06a	32.04 ± 4.00a	84.51 ± 1.37a
	C	20.93 ± 4.01a	13.93 ± 2.17a	38.91 ± 3.35a	2.93 ± 0.86c	76.71 ± 3.02a
Cheilanthes farinosa	A	10.08 ± 4.04b	9.15 ± 3.29a	22.00 ± 2.25a	30.72 ± 0.72a	71.96 ± 6.65a
	B	37.86 ± 5.15a	20.32 ± 6.35a	0.00 ± 0.00c	3.51 ± 0.96b	61.69 ± 11.69ab
	C	0.00 ± 0.00c	19.55 ± 1.88a	4.40 ± 0.25b	34.74 ± 3.54a	58.68 ± 5.03b
Cheilanthes opposita	A	0.00 ± 0.00b	23.62 ± 7.04a	6.40 ± 0.50a	51.15 ± 3.47a	81.17 ± 3.70a
	B	25.06 ± 3.04a	25.80 ± 1.65a	11.50 ± 1.28a	18.56 ± 3.46a	80.93 ± 1.22a
	C	21.34 ± 3.60a	25.27 ± 2.50a	8.62 ± 1.59a	26.14 ± 2.70a	81.37 ± 2.82a
Cheilanthes tenuifolia	A	14.69 ± 4.05a	20.65 ± 1.18a	14.06 ± 1.92a	31.95 ± 3.66a	81.34 ± 1.75a
	B	22.18 ± 7.77a	13.37 ± 2.65a	21.23 ± 3.74a	23.03 ± 4.26a	79.81 ± 2.35a
	C	12.67 ± 3.28a	16.03 ± 3.80a	16.14 ± 3.04a	34.06 ± 1.57a	78.90 ± 0.13a
Christella dentata	A	0.00 ± 0.00b	25.86 ± 3.39a	13.9 ± 4.29a	38.92 ± 6.30a	78.68 ± 2.25a
	B	18.86 ± 1.61a	16.28 ± 6.61a	17.30 ± 3.42a	29.45 ± 4.34ab	81.89 ± 2.52a
	C	22.79 ± 1.27a	21.95 ± 1.89a	14.42 ± 3.64a	19.31 ± 6.29b	78.48 ± 3.78a
Christella parasitica	A	29.33 ± 4.86a	13.18 ± 1.69a	20.30 ± 8.98a	22.71 ± 1.66a	85.53 ± 1.04a
	B	21.77 ± 2.88a	8.93 ± 2.26ab	23.88 ± 3.56a	25.36 ± 2.35a	79.95 ± 3.93a
	C	18.51 ± 5.05a	1.98 ± 1.21b	24.74 ± 1.70a	15.75 ± 4.19a	60.97 ± 4.60b
Cyathea gigantea	A	35.21 ± 2.13a	1.80 ± 1.56c	31.18 ± 0.29a	14.47 ± 0.50a	82.67 ± 1.76a
	B	29.55 ± 1.14a	8.71 ± 2.56b	24.37 ± 4.39a	17.02 ± 5.53a	79.64 ± 1.54a
	C	22.73 ± 2.95b	20.99 ± 1.48a	23.40 ± 2.18a	17.67 ± 3.86a	84.79 ± 2.69a
Dicranopteris linearis	A	30.01 ± 0.97a	0.00 ± 0.00c	37.95 ± 1.95a	14.84 ± 2.09a	82.80 ± 1.22a
	B	30.22 ± 2.46a	0.89 ± 0.44b	31.66 ± 6.55a	16.53 ± 5.21a	79.29 ± 4.38a
	C	22.49 ± 0.73a	5.57 ± 1.25a	38.89 ± 3.83a	16.82 ± 4.04a	83.76 ± 0.72a
Diplazium sylvaticum	A	23.17 ± 6.74a	23.97 ± 4.49	21.01 ± 4.52a	7.40 ± 3.80a	75.56 ± 6.17a
	B	35.92 ± 1.71a	30.58 ± 1.54	9.81 ± 2.69b	6.98 ± 3.10a	83.30 ± 1.20a
	C	26.28 ± 6.95a	22.24 ± 3.70	27.17 ± 4.36a	4.70 ± 3.18a	80.39 ± 5.05a
Diplazium polypodioides	A	25.92 ± 3.04a	16.39 ± 2.17a	31.58 ± 1.72a	5.14 ± 3.13a	79.03 ± 1.93a
	B	30.33 ± 1.38a	18.01 ± 2.20a	25.92 ± 2.02a	8.37 ± 1.57a	82.64 ± 1.31a
	C	25.15 ± 5.30a	19.50 ± 2.92a	25.98 ± 6.52a	10.80 ± 6.25a	81.44 ± 2.32a

TABLE 3. Continued.

Plant species	Site[a]	AM colonization[b]				
		%RLH	%RLV	%RLAC	%RLHC	%RLTC
Doryopteris concolor	A	29.60 ± 1.52a	12.52 ± 4.42b	33.26 ± 0.86a	7.32 ± 1.58a	82.71 ± 1.64a
	B	34.31 ± 0.44a	8.16 ± 5.13b	36.19 ± 5.66a	4.26 ± 2.17a	82.93 ± 1.46a
	C	28.37 ± 2.97a	25.90 ± 3.31a	21.76 ± 1.39a	9.00 ± 1.90a	85.03 ± 0.90a
Drynaria quercifolia	B	6.56 ± 3.81b	5.12 ± 3.69a	0.00 ± 0.00a	64.66 ± 6.67a	76.34 ± 1.16a
	C	37.77 ± 2.46a	0.00 ± 0.00b	0.46 ± 0.16a	10.18 ± 3.65b	48.40 ± 4.59b
Hemionitis arifolia	A	19.70 ± 1.46a	27.53 ± 3.40a	27.26 ± 0.58a	7.58 ± 2.85b	82.07 ± 1.44a
	B	25.82 ± 3.04a	19.76 ± 0.91a	34.27 ± 5.05a	0.75 ± 0.75c	80.59 ± 1.83a
	C	20.79 ± 4.58a	22.29 ± 2.63a	18.38 ± 2.99a	19.27 ± 3.93a	80.73 ± 3.36a
Lepisorus nudus	A	2.00 ± 2.89a	0.00 ± 0.00b	7.32 ± 0.25a	54.60 ± 2.80a	63.92 ± 4.59a
	B	0.00 ± 0.00b	3.25 ± 3.25a	10.82 ± 1.26a	31.24 ± 1.05b	45.31 ± 5.29b
	C	0.00 ± 0.00b	6.44 ± 2.37a	8.76 ± 1.12a	49.21 ± 4.91a	64.41 ± 6.41a
Leptochilus decurrens	A	0.00 ± 0.00b	26.06 ± 3.43a	2.24 ± 0.05b	50.41 ± 0.41a	78.71 ± 1.63a
	C	4.72 ± 1.53a	23.87 ± 6.86a	24.00 ± 3.34a	30.00 ± 2.25a	82.59 ± 8.37a
Lycodium microphyllum	A	16.90 ± 4.09a	7.65 ± 2.17a	36.86 ± 8.23a	20.61 ± 8.19a	82.02 ± 0.63a
	B	22.10 ± 1.48a	11.21 ± 5.85a	33.70 ± 3.41a	16.78 ± 7.58a	83.79 ± 1.06a
	C	25.50 ± 3.12a	7.27 ± 1.26a	37.59 ± 6.27a	11.38 ± 2.27a	81.75 ± 1.05a
Lycopodium cernuum	A	0.00 ± 0.00b	10.01 ± 2.36a	8.82 ± 1.03a	50.17 ± 4.79a	69.00 ± 3.52a
	B	3.96 ± 0.25a	2.44 ± 1.25b	5.00 ± 1.20a	53.15 ± 3.53a	64.55 ± 1.62a
Macrothelypteris torresiana	A	24.09 ± 5.92a	11.39 ± 3.25a	16.41 ± 5.47a	30.11 ± 9.95a	82.00 ± 1.37a
	B	20.98 ± 4.13a	14.78 ± 8.96a	18.47 ± 7.14a	29.05 ± 1.72a	83.27 ± 0.88a
	C	31.29 ± 4.39a	14.69 ± 5.32a	21.89 ± 1.10a	16.71 ± 3.04a	84.57 ± 0.32a
Marsilea minuta	A	0.00 ± 0.00a	0.00 ± 0.00b	8.94 ± 1.15a	42.80 ± 4.88a	51.74 ± 3.16c
	B	0.00 ± 0.00a	35.31 ± 1.84a	8.59 ± 1.02a	38.89 ± 1.54b	82.79 ± 1.49a
	C	0.00 ± 0.00a	31.83 ± 6.24a	7.00 ± 1.25a	37.73 ± 1.77ab	76.56 ± 1.73b
Marsilea quadrifolia	A	0.00 ± 0.00a	0.67 ± 0.17a	5.09 ± 0.50a	15.00 ± 1.15a	20.76 ± 4.54a
	B	0.00 ± 0.00a	2.10 ± 1.24a	5.62 ± 0.25a	10.00 ± 1.25a	17.72 ± 4.04a
Microlepia platyphylla	A	27.02 ± 4.00a	11.69 ± 1.61a	28.49 ± 2.82a	13.88 ± 2.49a	81.08 ± 1.32a
	B	19.48 ± 4.72a	13.51 ± 0.68a	28.82 ± 0.47a	18.83 ± 2.35a	80.65 ± 1.88a
Nephrolepis auriculata	A	27.36 ± 2.52a	8.03 ± 2.81b	33.84 ± 4.07a	9.70 ± 1.91a	78.93 ± 2.07a
	B	24.85 ± 1.14a	20.04 ± 6.40a	27.52 ± 6.07a	7.93 ± 0.26a	80.33 ± 2.38a

TABLE 3. Continued.

Plant species	Site[a]	AM colonization[b]				
		%RLH	%RLV	%RLAC	%RLHC	%RLTC
Nephrolepis multiflora	A	0.00 ± 0.00b	11.16 ± 6.35a	19.81 ± 4.90a	46.58 ± 3.51a	77.55 ± 4.08a
	B	8.75 ± 0.97a	0.00 ± 0.00b	7.14 ± 1.14a	57.91 ± 3.29b	73.81 ± 5.93a
	C	7.11 ± 1.53a	0.00 ± 0.00b	22.04 ± 2.25a	47.28 ± 4.17c	76.43 ± 1.66a
Pityrogramma calomelanos	A	12.00 ± 4.46a	18.01 ± 6.53a	26.47 ± 0.71a	14.81 ± 7.33a	71.28 ± 1.98a
	B	27.77 ± 2.95a	20.89 ± 0.61a	25.35 ± 2.23a	7.50 ± 3.67a	81.51 ± 2.54a
	C	24.17 ± 5.42a	20.71 ± 5.45a	26.00 ± 0.61a	10.07 ± 3.20a	80.95 ± 3.17a
Pseudocyclosorus xylodes	A	26.85 ± 3.75a	17.41 ± 5.13a	1.98 ± 1.40ab	25.62 ± 4.16a	71.86 ± 6.65a
	B	20.48 ± 4.57a	36.10 ± 3.35a	4.89 ± 2.46a	9.37 ± 4.20b	70.84 ± 4.48a
	C	25.36 ± 4.81a	24.55 ± 4.11a	0.92 ± 0.12b	17.71 ± 4.52ab	68.55 ± 4.57a
Pseudocyclosorus ochthodes	A	7.00 ± 3.55b	33.27 ± 4.88a	10.00 ± 1.50a	34.16 ± 4.03a	84.44 ± 0.27a
	B	5.73 ± 1.88c	32.66 ± 5.44a	0.00 ± 0.00b	42.17 ± 4.66a	80.55 ± 1.31a
	C	9.85 ± 0.33a	25.89 ± 4.15a	0.00 ± 0.00b	46.48 ± 5.21a	82.22 ± 2.08a
Pteridium aquilinum	B	27.68 ± 3.11a	10.78 ± 1.55a	10.14 ± 2.19a	33.18 ± 3.21a	81.79 ± 4.47a
	C	22.84 ± 3.65a	11.05 ± 2.07a	13.00 ± 2.22a	34.47 ± 2.63a	81.36 ± 2.14a
Pteris biaurita	A	25.53 ± 2.18a	21.61 ± 1.11a	18.23 ± 1.35a	18.55 ± 0.72a	83.93 ± 0.66a
	B	18.82 ± 1.55a	19.88 ± 2.65a	17.59 ± 2.13a	24.36 ± 2.53a	80.64 ± 2.28a
	C	24.13 ± 2.62a	12.72 ± 6.54a	24.86 ± 5.53a	20.68 ± 3.85a	82.38 ± 0.79a
Pteris pellucida	A	24.09 ± 1.97a	11.43 ± 2.42a	22.80 ± 2.93a	22.62 ± 0.73a	80.94 ± 2.13a
	B	19.35 ± 1.69a	23.39 ± 2.50a	17.35 ± 5.34a	19.07 ± 3.56a	79.17 ± 2.54a
	C	24.07 ± 4.26a	18.93 ± 2.93a	23.65 ± 2.96a	15.43 ± 6.19a	82.09 ± 0.92a
Pyrrosia lanceolata	A	24.74 ± 8.61a	0.00 ± 0.00a	0.00 ± 0.00a	38.87 ± 4.30a	63.61 ± 5.99a
	B	31.55 ± 2.92a	0.00 ± 0.00a	0.00 ± 0.00a	27.08 ± 3.87a	58.63 ± 4.49a
	C	27.16 ± 6.13a	0.00 ± 0.00a	0.00 ± 0.00a	33.00 ± 0.89a	60.16 ± 5.63a
Selaginella sp.	C	12.19 ± 5.20b	0.35 ± 0.35a	11.55 ± 0.74a	50.81 ± 4.75a	74.90 ± 4.22a
Selaginella wightii	A	24.53 ± 2.02a	0.00 ± 0.00b	9.62 ± 1.30a	42.94 ± 2.55a	77.09 ± 3.16a
	A	27.49 ± 5.24a	12.27 ± 6.14a	20.00 ± 2.25a	23.25 ± 0.53a	83.01 ± 1.34a
	B	23.93 ± 3.90a	6.70 ± 3.38a	21.00 ± 1.75a	14.93 ± 1.62a	66.56 ± 2.61a
	C	29.62 ± 3.27a	12.46 ± 4.57a	19.00 ± 1.25a	6.53 ± 6.53a	67.62 ± 7.84a
Sphaerostephanos arbuscula	A	22.02 ± 0.84a	21.44 ± 4.36a	20.70 ± 1.62a	21.74 ± 1.67a	65.96 ± 0.60b
	B	20.61 ± 2.52a	26.20 ± 8.11a	13.55 ± 6.30a	21.98 ± 3.18a	82.33 ± 1.43a
	C	21.21 ± 3.74a	30.64 ± 1.53a	20.48 ± 1.32a	9.22 ± 1.68b	81.56 ± 2.53a

TABLE 3. Continued.

Plant species	Site[a]	AM colonization[b]				
		%RLH	%RLV	%RLAC	%RLHC	%RLTC
Sphenomeris chinensis	A	32.14 ± 4.45a	12.43 ± 5.02a	18.81 ± 1.57a	20.36 ± 0.99a	83.74 ± 2.83a
	B	31.71 ± 5.31a	12.27 ± 5.02a	20.41 ± 4.71a	20.30 ± 4.59a	84.69 ± 0.59a
	C	24.21 ± 1.95a	17.57 ± 2.26a	15.02 ± 1.70a	27.28 ± 2.63a	84.08 ± 0.57a
Tectaria coadunata	A	17.96 ± 3.62a	24.31 ± 3.56a	16.72 ± 6.07b	19.90 ± 2.74b	78.88 ± 3.23a
	B	16.85 ± 1.21a	10.02 ± 2.31b	30.75 ± 1.20a	23.66 ± 0.87a	81.28 ± 2.96a
Vittaria elongata	A	33.13 ± 3.73a	17.47 ± 2.78a	9.26 ± 1.77b	5.47 ± 2.16a	65.32 ± 8.40b
	B	31.37 ± 0.67a	9.52 ± 1.98b	26.09 ± 2.50a	8.79 ± 2.39a	75.77 ± 1.41a

[a] A, Solakkadu; B, Kuzhivalavu shola; C, Nachiyar kovil.
[b] RLH, Root length with hyphae; RLA/AC, Root length with arbuscules/arbusculate coils; RLV, Root length with vesicles; RLC, Root length with hyphal coils; RLTC, Root length with total colonization.
* Mean ± S.E in a column for a species followed by the same letter(s) are not significantly different.

TABLE 4. Distribution of arbuscular mycorrhizal fungal species in different study sites in the Kolli Hills (+, presence; −, absence)

AM fungal species	Site A[a]	Site B	Site C
Acaulospora foveata	+	−	−
Acaulospora rehmii	+	−	+
Acaulospora scrobiculata	+	+	+
Funneliformis constrictum	+	−	−
Funneliformis geosporum	+	+	+
Gigaspora decipiens	−	−	+
Glomus invermaium	+	−	+
Glomus microcarpum	+	+	+
Sclerocystis rubiformis	+	−	+
	8	3	7

[a] A, Solakkadu; B, Kuzhivalavu shola; C, Nachiyar kovil.

Occurrence of DSE fungal association.—Dark septate endophyte fungal colonization, characterized by melanized or hyaline septate hyphae, microsclerotia and moniliform cells in root cortex was observed in 33 ferns (Table 1, Fig. 4a–h). However, DSE fungal structures were absent in the three lycophytes and 11 fern taxa belonging to nine families. These included *Adiantum capillus*

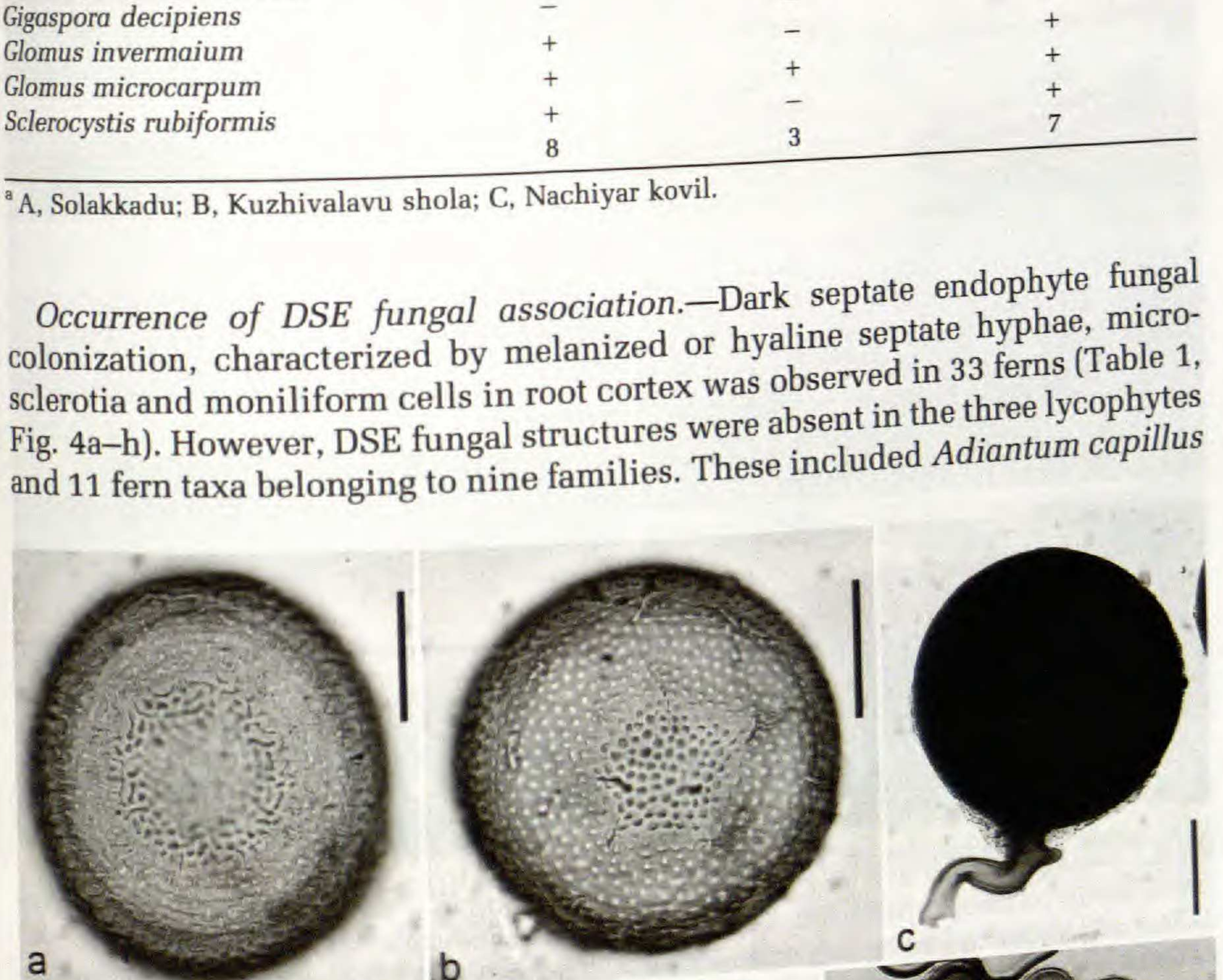

FIG. 3. a–h. Arbuscular mycorrhizal spores isolated from the substrates of ferns. a. Spore of *Acaulospora rehmii*, b. Spore of *Acaulospora foveata*, c. Spore of *Funneliformis geosporum*, d. Spores of *Glomus microcarpum*; g. Fractured spore of *Gigaspora decipens*; h. Spores of *Sclerocystis rubiformis*. Scale bars=50 µm.

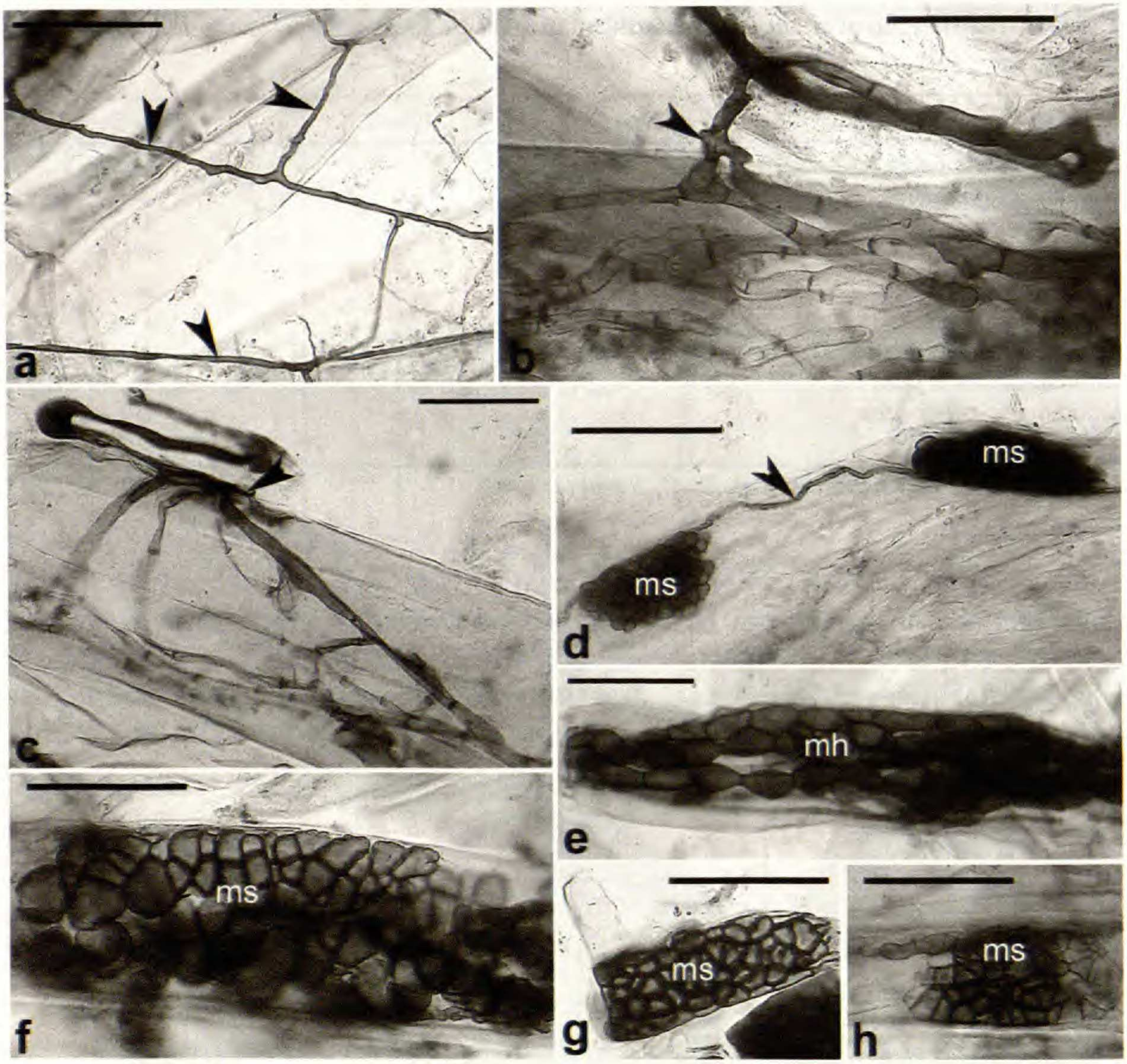

FIG. 4. a–h. Dark septate endophyte (DSE) fungal association in ferns. (a) Surface runner hyphae (arrow heads) on roots of *Adiantum incisum*; (b) Appresorium-like structure (arrow head) on root surface and septate hyphae in root cells of *Christella parasitica*; (c) Hyphal entry (arrow head) in *Chilanthes oppositia*; (d) Microsclerotia (ms) and the connecting hyphae (arrow head) in *Pityrogramma calomelanos*; (e) Moniliform cells in the root cortical cell of *Cheilanthes tenuifolia*. f–h. Microsclerotia (ms) in *Asplenium indicum* (f), *Adiantum hispidulum* (g), and *Lepisorus nudus* (h). Scale bars=50 μm.

(Adiantaceae), *A. pinnata*, *B. occidentale*, *Microlepia platyphylla*, *Pteridium aquilinum* (Dennstaediaceae), *Dicranopteris linearis* (Gleicheniaceae), *L. cernuum*, *M. minuta*, *M. quadrifolia*, *Selaginella* sp., *Selaginella wightii* (Selaginellaceae), *Christella dentata*, *P. xylodes* and *Sphaerostephanos arbuscula* (Thelypteridaceae) (Table 1).

Extent of DSE fungal colonization.—The root length colonized by DSE fungal hyphae ranged from 0.13% (*Pseudocyclosorus ochthodes*, Thelypteridaceae) to 11.95% (*Christella parasitica*, Thelypteridaceae) (Table 2). The percentage root length with moniliform cells ranged from 0.11% (*Pteris*

pellucida, Pteridaceae) to 4.53% (*Adiantum hispidulum*, Adiantaceae). The percentage root length with microsclerotia ranged from 0.14% (*Lygodium microphyllum*, Schizaeaceae) to 22.73% (*D. quercifolia*). The percentage and root length with total DSE colonization ranged from 0.14% (*L. microphyllum*) to 27.40% (*D. quercifolia*) (Table 2). The percentage root length with total DSE fungal colonization and root length with DSE fungal structures in *Asplenium tenuifolium* (Aspleniaceae), *C. tenuifolia*, *C. parasitica* and *V. elongata* varied significantly among sites. Significant differences existed in average percentage root length with total DSE colonization (H_4=73.16, P<0.001) among various life-forms (Fig. 2b), with epiphytic ferns (14.74%) possessing maximum average percentage root length with total DSE fungal colonization and terrestrial species (3.05%) recording the minimum percentage root length with total DSE fungal colonization. Ferns examined from the marshy and aquatic habitats lacked DSE fungal colonization. However, percentage root length with total DSE colonization and root length with DSE fungal structures varied significantly among plant species and sites except for percent root length with DSE fungal hyphae (Table 2, 5). The species × site interactions were also significant for all the DSE fungal variables examined. Although a significant negative correlation existed between percentage root length with total DSE and AM fungal colonization (r = −0.269, p<0.01, n=130), the linear association accounted only for 7.2% of the variance in the two variables.

Discussion

Our results showed the frequent occurrence of AM association in lycophytes and ferns of the Kolli Hills. This is in agreement with an earlier study (Muthukumar and Prabha, 2013) where 24 of 26 species of ferns examined from the Yercaud hills of the Eastern Ghats, south India were found to be colonized by AM fungi. Surveys from many habitats worldwide indicate both high (>75%) and low (<50%) incidence of AM in lycophytes and ferns (see Muthukumar and Prabha, 2013, and references therein). To our knowledge, AM association has been reported in 15 ferns and two lycophyte species for the first time here. The lack of AM association in the aquatic fern *A. pinnata* is consistent with previous observations of the aquatic ferns *Azolla* and *Salvinia* (Gemma *et al.*, 1992; Lee *et al.*, 2001; Muthukumar and Udaiyan, 2000; Ragupathy and Mahadevan, 1993). The non-mycotrophic nature of the free floating aquatic fern *A. pinnata* could be due to two causes. First, as the fern floats freely in water throughout the year, it has no chance of contacting mycorrhizal inocula of any type unless it drifts to the shores. Second, hydrophytes generally have a poorly developed root system as the necessary nutrients could be absorbed directly by roots and shoot surfaces that are in contact with water (Radhika and Rodrigues, 2007).

In contrast to *A. pinnata*, *M. quadrifolia* and *M. minuta* examined from marshy habitats in the present study were colonized by AM fungi, which corroborates previous findings (Bajwa *et al.*, 2001; Bareen, 1990; Iqbal *et al.*, 1988; Radhika and Rodrigues, 2007). As soil moisture levels in marshy habitats

TABLE 5. Extent of dark septate entophyte (DSE) fungal colonization in lycophytes and ferns at different sites of the Kolli Hills.

Plant species	Site[#]	DSE Colonization[##] %RLDSH	%RLMO	%RLMI	%RLDTC
Adiantum hispidulum	A	0.49 ± 0.19a*	4.09 ± 0.09a	—	4.58 ± 1.87a
	B	0.00 ± 0.00b	7.41 ± 0.41a	—	7.41 ± 0.41a
	C	0.44 ± 0.14a	2.08 ± 0.30a	—	2.52 ± 0.74a
Adiantum capillus	A	—	—	—	—
	B	—	—	—	—
	C	—	—	—	—
Adiantum incisum	A	0.43 ± 0.13a	—	4.65 ± 3.04a	5.08 ± 3.45a
	B	0.00 ± 0.00b	—	1.69 ± 0.90a	1.69 ± 0.90a
	C	0.00 ± 0.00b	—	3.43 ± 0.89a	3.43 ± 0.89a
Adiantum raddianum	A	0.50 ± 0.05a	0.89 ± 0.19a	—	1.39 ± 0.77a
	B	0.00 ± 0.00b	0.00 ± 0.00b	—	0.00 ± 0.00b
	C	0.53 ± 0.03a	0.00 ± 0.00b	—	0.53 ± 0.03a
Angiopteris evecta	A	0.31 ± 0.11a	0.00 ± 0.00b	—	0.31 ± 0.11a
	B	2.94 ± 0.87a	0.65 ± 0.15a	—	3.59 ± 1.35a
	C	0.77 ± 0.39a	0.00 ± 0.00b	—	0.77 ± 0.39a
Azolla pinnata	A	—	—	—	—
	C	—	—	—	—
Arachniodes amabilis	A	1.32 ± 0.66a	—	—	1.32 ± 0.66a
	B	0.00 ± 0.00b	—	—	0.00 ± 0.00b
	C	0.00 ± 0.00b	—	—	0.00 ± 0.00b
Asplenium indicum	A	1.34 ± 0.75a	—	—	1.34 ± 0.75a
	B	2.31 ± 1.36a	—	—	2.31 ± 1.36a
	C	2.33 ± 0.33a	—	—	2.33 ± 0.33a
Asplenium lanceolatum	C	4.14 ± 0.97a	0.67 ± 0.17a	12.46 ± 1.80ab	17.27 ± 2.94a
	A	3.81 ± 0.19a	0.00 ± 0.00b	5.54 ± 1.78b	9.35 ± 1.85a
	B	8.86 ± 2.01a	0.00 ± 0.00b	0.40 ± 0.20a	9.26 ± 2.02a
Asplenium tenuifolium	A	7.99 ± 2.93a	3.61 ± 0.69a	12.05 ± 4.00a	23.66 ± 4.06a
	B	1.09 ± 0.55b	0.00 ± 0.00b	1.02 ± 0.02a	2.11 ± 0.49b
	C	2.92 ± 0.62ab	0.00 ± 0.00b	2.33 ± 1.38a	5.25 ± 0.95b
Blechnum occidentale	A	—	—	—	—
	B	—	—	—	—
	C	—	—	—	—
Ceratopteris thalictroides	A	0.00 ± 0.00b	0.00 ± 0.00b	—	0.00 ± 0.00b
	B	2.89 ± 0.57a	1.09 ± 0.09a	—	3.98 ± 2.02a
	C	0.00 ± 0.00b	0.00 ± 0.00b	—	0.00 ± 0.00b
Cheilanthes farinosa	A	2.76 ± 0.70a	—	6.31 ± 4.32a	9.07 ± 5.01a
	B	2.83 ± 1.50a	—	4.38 ± 1.76a	7.22 ± 2.82a
	C	1.80 ± 0.80a	—	4.32 ± 0.89a	6.12 ± 2.44a
Cheilanthes opposita	A	0.48 ± 0.18a	—	—	0.48 ± 0.18a
	B	2.92 ± 0.89a	—	—	2.92 ± 0.90a
	C	2.34 ± 1.62a	—	—	2.34 ± 1.62a
Cheilanthes tenuifolia	A	0.71 ± 0.36c	1.95 ± 0.46a	2.28 ± 0.57a	4.94 ± 0.77a
	B	3.53 ± 0.23a	0.42 ± 0.42a	1.34 ± 0.73a	5.29 ± 0.98a
	C	2.10 ± 0.41b	0.54 ± 0.14a	6.71 ± 1.65a	9.35 ± 1.50a
Christella dentata	A	—	—	—	—
	B	—	—	—	—
	C	—	—	—	—

TABLE 5. Continued.

Plant species	Site[#]	DSE Colonization[##] %RLDSH	%RLMO	%RLMI	%RLDTC
Christella parasitica	A	7.14 ± 2.14b	—	1.78 ± 0.78a	8.92 ± 3.74b
	B	0.00 ± 0.00c	—	0.00 ± 0.00 b	0.00 ± 0.00c
	C	28.71 ± 3.36a	—	4.40 ± 0.55a	33.11 ± 3.20a
Cyathea gigantea	A	7.99 ± 1.91a	0.49 ± 0.19a	—	8.48 ± 2.08a
	B	3.90 ± 1.85a	0.00 ± 0.00b	—	3.90 ± 1.85a
	C	5.45 ± 0.93a	0.72 ± 0.22a	—	6.17 ± 0.76a
Dicranopteris linearis	A	—	—	—	—
	B	—	—	—	—
	C	—	—	—	—
Diplazium sylvaticum	A	—	0.37 ± 0.07a	1.50 ± 0.50a	1.87 ± 0.87a
	B	—	0.00 ± 0.00b	0.74 ± 0.04a	0.74 ± 0.04a
	C	—	0.55 ± 0.15a	0.00 ± 0.00b	0.55 ± 0.15a
Diplazium polypodioides	A	0.00 ± 0.00b	—	1.34 ± 0.80a	1.34 ± 0.80a
	B	0.00 ± 0.00b	—	1.11 ± 0.56a	1.11 ± 0.56a
	C	1.92 ± 1.05a	—	4.11 ± 2.20a	6.03 ± 3.04a
Doryopteris concolor	A	0.65 ± 0.15a	—	—	0.65 ± 0.15a
	B	3.82 ± 1.82a	—	—	3.82 ± 1.82a
	C	0.00 ± 0.00b	—	—	0.00 ± 0.00b
Drynaria quercifolia	B	2.86 ± 0.58a	0.00 ± 0.00b	15.07 ± 9.27a	17.93 ± 9.63a
	C	2.59 ± 1.57a	3.89 ± 2.49a	30.39 ± 6.60a	36.87 ± 8.20a
Hemionitis arifolia	A	0.40 ± 0.02a	—	—	0.40 ± 0.02a
	B	0.00 ± 0.00b	—	—	0.00 ± 0.00b
	C	1.15 ± 0.59a	—	—	1.15 ± 0.59
Lepisorus nudus	A	3.41 ± 0.68a	—	19.81 ± 2.19a	23.22 ± 2.65a
	B	6.61 ± 2.09a	—	22.28 ± 3.84a	28.89 ± 5.42a
	C	3.41 ± 1.49a	—	15.12 ± 3.74a	18.37 ± 5.16a
Leptochilus decurrens	A	0.85 ± 0.57a	4.47 ± 0.89a	—	5.32 ± 1.10a
	C	0.00 ± 0.00b	3.17 ± 0.77a	—	3.17 ± 0.77a
Lygodium microphyllum	A	—	—	0.00 ± 0.00b	0.00 ± 0.00b
	B	—	—	0.42 ± 0.12a	0.42 ± 0.12a
	C	—	—	0.00 ± 0.00b	0.00 ± 0.00b
Lycopodium cernuum	A	—	—	—	—
	B	—	—	—	—
Macrothelypteris torresiana	A	0.00 ± 0.00b	1.67 ± 0.67a	—	1.67 ± 0.67a
	B	1.80 ± 0.80a	0.00 ± 0.00b	—	1.80 ± 0.80a
	C	0.00 ± 0.00b	0.79 ± 0.19a	—	0.79 ± 0.19a
Marsilea minuta	A	—	—	—	—
	B	—	—	—	—
	C	—	—	—	—
Marsilea quadrifolia	A	—	—	—	—
	B	—	—	—	—
Microlepia platyphylla	A	—	—	—	—
	B	—	—	—	—
Nephrolepis auriculata	A	1.40 ± 0.63b	—	—	1.40 ± 0.63b
	B	3.24 ± 0.94a	—	—	3.24 ± 0.94a
Nephrolepis multiflora	A	—	—	3.87 ± 0.39a	3.87 ± 0.39a
	B	—	—	0.00 ± 0.00b	0.00 ± 0.00b
	C	—	—	3.67 ± 1.95a	3.67 ± 1.95a

TABLE 5. Continued.

Plant species	Site[#]	DSE Colonization[##] %RLDSH	%RLMO	%RLMI	%RLDTC
Pityrogramma calomelanos	A	0.00 ± 0.00b	0.84 ± 0.14a	0.00 ± 0.00b	0.84 ± 0.14a
	B	0.00 ± 0.00b	0.00 ± 0.00b	0.77 ± 0.39a	0.77 ± 0.39a
	C	0.67 ± 0.17a	0.00 ± 0.00b	1.95 ± 1.03a	2.61 ± 0.46a
Pseudocyclosorus xylodes	A	—	—	—	—
	B	—	—	—	—
	C	—	—	—	—
Pseudocyclosorus ochthodes	A	0.00 ± 0.00b	0.42 ± 0.12a	—	0.42 ± 0.12a
	B	0.39 ± 0.09a	0.00 ± 0.00b	—	0.39 ± 0.09a
	C	0.00 ± 0.00b	0.00 ± 0.00b	—	0.00 ± 0.00b
Pteridium aquilinum	B	—	—	—	—
	C	—	—	—	—
Pteris biaurita	A	1.61 ± 1.09a	0.38 ± 0.18a	1.59 ± 0.35a	3.58 ± 1.16a
	B	2.71 ± 1.51a	0.00 ± 0.00b	2.02 ± 1.01a	4.73 ± 2.47a
	C	1.99 ± 1.10a	0.00 ± 0.00b	2.41 ± 1.47a	4.40 ± 2.56a
Pteris pellucida	A	0.41 ± 0.11a	0.00 ± 0.00b	—	0.41 ± 0.11a
	B	0.32 ± 0.02a	0.32 ± 0.02a	—	0.64 ± 0.03a
	C	0.89 ± 0.19a	0.00 ± 0.00b	—	0.89 ± 0.19a
Pyrrosia lanceolata	A	0.00 ± 0.00b	—	14.91 ± 0.60a	14.91 ± 0.60a
	B	0.00 ± 0.00b	—	27.69 ± 8.00a	27.69 ± 8.00a
	C	2.38 ± 0.38a	—	15.49 ± 0.79a	17.87 ± 1.85a
Selaginella sp.	A	—	—	—	—
	C	—	—	—	—
Selaginella wightii	A	—	—	—	—
	B	—	—	—	—
	C	—	—	—	—
Sphaerostephanos arbuscula	A	—	—	—	—
	B	—	—	—	—
	C	—	—	—	—
Sphenomeris chinensis	A	1.16 ± 0.68ab	—	—	1.16 ± 0.68ab
	B	5.62 ± 1.62a	—	—	5.62 ± 1.62a
	C	0.00 ± 0.00b	—	—	0.00 ± 0.00b
Tectaria coadunata	A	2.31 ± 0.48a	—	4.21 ± 1.06a	6.52 ± 1.09a
	B	3.68 ± 2.92a	—	4.60 ± 2.49a	8.28 ± 5.41a
Vittaria elongata	A	6.09 ± 1.16a	1.93 ± 0.70a	17.37 ± 8.40a	25.39 ± 9.66a
	B	1.13 ± 0.58a	1.77 ± 1.12a	0.00 ± 0.00b	2.90 ± 1.66b

[#] A, Solakkadu; B, Kuzhivalavu shola; C, Nachiyar kovil.

[##] RLDSH, Root length with dark septate fungal hyphae; RLMI/MO, Root length with microsclerotia/ moniliform hyphae; RLDTC, Root length with total colonization.

* Means ± SE followed by same alphabet(s) for a species are not significantly different.

vary with environmental conditions, plants can acquire AM colonization during drier seasons and subsequent flooding may not affect the colonization levels within roots (Miller and Sharitz, 2000). This may be the reason for the prevalence of AM fungal colonization in both the *Marsilea* species observed from marshy habitats. The significant variation in the percentage root length among the two marshy ferns is consistent with the findings of Bajwa *et al.* (2001) who reported intense colonization in *M. minuta* during spring and summer.

Plant life-forms significantly affected the intensity of AM colonization. The average percentage root length with total AM fungal colonization of different life-forms was in the order of terrestrial > saxicolous > epiphytes > marshy plants. These results are in agreement with those of Fernández *et al.* (2012) and Gemma and Koske (1995) where the incidence and intensity of AM was reported to be higher for terrestrial species compared to other life-forms. All epiphytic and saxicolous taxa observed in the present study were mycorrhizal as previously observed (Gemma and Koske, 1995; Muthukumar and Prabha, 2013; Muthukumar and Udaiyan, 2000). Nevertheless, epiphytic or saxicolous pteridophytes are often reported to be non-mycorrhizal or facultatively mycorrhizal in other studies (Berch and Kendrick, 1982; Fernandez *et al.*, 2010, Zubek *et al.*, 2010). Lycophytes and ferns growing on bare branches or rocks are frequently exposed to changes in water supply, as water holding capacities of these surfaces are very low (Hietz, 2010). Furthermore, in these extreme environments, high temperature along with strong wind currents may dry these surfaces quite rapidly resulting in vegetative desiccation (Oliver *et al.*, 2000). Therefore, lycophytes and ferns existing on these habitats could depend more on AM fungi for water and nutrients under these stressful conditions as the association has been shown to ameliorate water stress (Smith and Smith, 2011). The lack of AM propagules has often been cited as a cause for the low incidence of AM in epiphytic and lithophytic habitats. Nevertheless, birds and animals could easily bring in the AM fungal propagules to these extreme environments (Gemma *et al.*, 1992; Gemma and Koske, 1995). In addition, AM fungal propagules could reach rock surfaces and rock crevices through the movement of overhead dry soil, dispersal of mycorrhizal root fragments by wind activity, and surface runoffs carrying eroded soil (Berch and Kendrick, 1982).

Root colonization directly through the rhizodermis and the presence of AM fungal hyphae within root hairs supports earlier observations (Berch and Kendrick, 1982; Cooper, 1976; Fernández *et al.*, 2012) where this phenomenon has been documented in lycophytes and ferns. Likewise, the morphologically distinct types of intraradical AM fungal hyphae seen in roots have been reported in vascular plants including ferns (Bentivenga and Morton, 1995; Fernández *et al.*, 2012; Merryweather and Fitter, 1998). Arbuscule formation on the intraradical hyphae or hyphal coils varied from very limited (e.g., *L. nudus*, *Diplazium sylvaticum*, Woodsiaceae) to more elaborate (e.g., *A. incisum*, *B. occidentale*) forms. These observations suggests the colonization of pteridophyte roots by different AM fungal taxa as previously shown by both conventional (root squash) and molecular studies (Muthukumar *et al.*, 2009; West *et al.*, 2009).

The consistent presence of mycorrhizae as evidenced by the presence of fungal structures in all the individuals of leptosporangiate ferns similar to the observations of Lee *et al.* (2001) and Fernandez *et al.* (2012), fails to support Boullard's (1979) hypothesis that mycotrophy was inconsistent in the advanced leptosporangiate ferns and Zhao's (2000) suggestion that the most recent common ancestor of pteridophytes was non-mycotrophic. In the present

study, the extent of AM fungal colonization and root length with different AM fungal structures showed significant variations among species which is in line with the results from earlier studies (Khade and Rodrigues, 2002; Muthukumar and Prabha, 2013; Muthukumar and Udaiyan, 2000; Prashar *et al.*, 2005). As AM fungal colonization and formation of AM fungal structures are an interaction of host, fungal and environmental factors, the observed variations in colonization and AM fungal structures among species is reasonable. The higher average percentage total AM colonization in lycophytes compared to ferns is comparable to some of the previous reports for these taxa (Gemma *et al.*, 1992; Kessler *et al.*, 2010a; Muthukumar and Prabha, 2013). The high average percentage root length with total AM colonization in leptosporangiate ferns (74.03%) do not support Boullard's (1979) view that leptosporangiate ferns with fine roots are less colonized compared to eusporangiate pteridophytes with relatively thick roots.

Arbuscular mycorrhizal fungal morphology has been reported for the first time in 33 lycophytes and ferns examined in the study. The intermediate- and *Paris*-type colonization patterns found in lycophytes and ferns of the Kolli Hills are in agreement with observations for pteridophytes in general (Dickson *et al.*, 2007; Muthukumar and Prabha, 2013). This is not surprising because ferns and lycophytes are generally perennial, slow-growing, and often occur in stressful habitats (low light, highly fluctuating moisture and nutrients), where possessing *Paris*- or intermediate-type AMs may be beneficial in reducing the host's energy cost (Dickson *et al.*, 2007). The frequent (72%, 34/47) occurrence of intermediate-type AM morphology in lycophytes and ferns of the Kolli Hills contradicts many studies where AM colonization patterns in lycophytes and ferns were dominated by *Arum*- or *Paris*-type AM morphology (Kessler *et al.*, 2010a; Zubek *et al.*, 2010). The intermediate-type AM morphology observed in *Pityrogramma calomelanos* (Adiantaceae), *P. aquilinum*, *Sphenomeris chinensis* (Lindsaeaceae), *D. linearis*, *P. pellucida* and *C. parasitica* is consistent with earlier observations (Muthukumar and Prabha, 2013). However, Zhang *et al.* (2004) reported *Paris*-type AM morphology in *P. aquilinum*, from Dujiangyan, southwest China. The two *Selaginella* species examined from different sites intermediate-type AM morphology. However, AM morphological patterns tend to differ among species in *Selaginella* as shown by Zhang *et al.* (2004) and Muthukumar and Prabha (2013). Regardless of habitat, 15% of the ferns had both *Paris*- and intermediate-type AM morphologies at different sites similar to the observations of Muthukumar and Prabha (2013). It must be emphasized that the factors controlling AM colonization patterns in roots are not well resolved. It has been proposed that the presence or absence of intercellular spaces in the root cortex are determinants of AM colonization patterns (Brundrett and Kendrick, 1990). Studies (Cavagnaro *et al.*, 2001a,b; Smith *et al.*, 2004) have shown that fungal identity can also influence AM fungal morphological patterns. Further, environmental factors like temperature, light intensity and soil moisture that affect plant growth, especially root growth, are presumed to influence AM colonization patterns within roots (Becerra *et al.*, 2007; Yamato, 2004; Yamato and Iwasaki, 2002). Hence, a more

detailed study on the various factors influencing AM colonization in roots is needed to understand the factors that determine colonization patterns in roots.

Diversity of AM fungi associated with lycophytes and ferns is very limited compared to the information on the prevalence of the association (Gosh *et al.*, 2012; Muthukumar *et al.*, 2009; Muthukumar and Prabha, 2013; Muthukumar and Udaiyan, 2000; Zhang *et al.*, 2004). The presence of nine AM fungal spore morphotypes of five genera is comparable to the results of previous studies where low AM fungal spore diversity has been reported for lycophytes and ferns (Ghosh *et al.*, 2012; Muthukumar and Prabha, 2013). In contrast, Zhang *et al.* (2004) reported the presence of 40 AM fungal spore morphotypes belonging to five genera from the rhizosphere of ferns and lycophytes of Dujiangyan, South west China. In the present study, spore numbers were very low (data not presented) with spores being absent in many of the substrate samples. Even among the recovered spores, most were devoid of spore contents and/or were parasitized by soil organisms. The infrequent presence of AM fungal spores did not affect the AM status or colonization rate as evidenced by moderate to high levels of colonization in all the mycorrhizal lycophytes and ferns. This clearly suggests that AM fungi perennate in the studied habitats through propagules other than spores (Smith and Read, 2008). Contrary to the general observations in tropical soils, species diversity was higher in *Acaulospora* than in *Glomus*.

Colonization of roots by DSE fungi has been reported in several plant species, including ferns and lycophytes (Fernandez *et al.*, 2012; Jumpponen and Trappe, 1998; Muthukumar and Prabha, 2013). Roots of 75% (33 of 44 species) of ferns belonging to 15 families were colonized by DSE fungi which corroborate the observations of Rains *et al.* (2003), where most of the 18 plant taxa, consisting of epiphytes and terrestrial species, in a neotropical rain forest in Costa Rica had DSE fungal associations. The DSE fungal associations have been reported for the first time in 28 ferns and corroborated for *Angiopteris evecta* (Marattiaceae), *O. chinensis*, *Diplazium polypodioides* (Woodsiaceae) and *P. pellucida* examined in this study (Jumpponen and Trappe, 1998; Muthukumar and Prabha, 2013). *Lycopodium cernuum* and *P. aquilinum* reported to possess DSE fungal association by Muthukumar and Prabha (2013) lacked the association in the present study. Co-occurrence of AM and DSE fungi within roots was observed in 33 ferns. Such dual association of AM and DSE fungi has been reported in a wide range of higher vascular plant species as well as for ferns (Chaudhry *et al.*, 2009; Fernández *et al.*, 2012; Muthukumar *et al.*, 2006; Muthukumar and Prabha, 2013). In contrast to AM fungal colonization, average percentage root length with total DSE fungal colonization was significantly higher in epiphytes compared to saxicolous and terrestrial taxa. Christie and Kilpatrick (1992) suggested that the DSE fungal association in lycophytes and ferns tend to take over the functions of AM fungi during conditions unfavourable for AM fungi. This suggestion could be realized from the observations of a recent study (Muthukumar and Prabha, 2012) where gametophytes and young sporophytes of *Nephrolepis exaltata* growing on soilless substrates like coir or bricks were predominantly colonized by DSE

fungi. In the present study, all the ferns examined from the epiphytic habitats had dual association of AM and DSE, which is almost similar to the findings of Lehnert *et al.* (2009) in ferns from southern Ecuador. The existence of a weak negative correlation between the percentage total root length colonized by AM and DSE fungi suggests competition by the two endophytic fungal types (Wu *et al.*, 2009). Although, the role of DSE fungi on lycophyte and fern growth is yet to be examined, a recent meta-analysis of plant responses to DSE fungal association suggests that the DSE fungi could improve plants performance under controlled conditions (Newsham, 2011).

In conclusion, the present study clearly shows the wide-spread occurrence of AM and DSE fungal associations in lycophytes and ferns of the Eastern Ghats. Many ferns examined in this study are routinely used for medicinal purposes and some are listed as threatened species. All these taxa were associated with AM and/or DSE fungi in the present study. Although, *A. evecta*, *Cyathea gigantea* (Cyatheaceae), *Ceratopteris thalictroides* (Pakeriaceae), *D. quericifolia* and *M. minuta* were reported in IUCN's Red List as threatened or rare taxa (Walter and Gillett, 2008), a recent reassessment of these taxa indicates that they are neither threatened nor rare (Chandra *et al.*, 2008). As Bothe *et al.* (2010) suggested, a potential exists for the use of AM and/or DSE fungi to promote the growth and fitness of threatened plant taxa. Therefore, conservation management techniques for ferns such as micropropagation could involve these fungi during an acclimatization phase as AM and DSE fungi are shown to be very efficient bio hardening agents for successful acclimatization (Kapoor *et al.*, 2008). Further research is needed to focus on the utilization of AM and DSE fungi in conservation of fern diversity in the Eastern Ghats.

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